Kentucky Geological Survey

Annual Report

University of Kentucky

Fiscal Year
1993-1994

1993–1994
ANNUAL REPORT

KENTUCKY GEOLOGICAL SURVEY
UNIVERSITY OF KENTUCKY
LEXINGTON, KENTUCKY

Donald C. Haney, State Geologist and Director

John D. Kiefer, Assistant State Geologist for Administration

James C. Cobb, Assistant State Geologist for Research

RESEARCH AND ADMINISTRATIVE OFFICES
228 Mining and Mineral Resources Building
University of Kentucky
Lexington, Kentucky 40506–0107
Phone (606) 257–5500

UNIVERSITY OF KENTUCKY
Charles T. Wethington, Jr., President
Delwood C. Collins, Acting Vice President for Research and Graduate Studies
Jack Supplee, Director, Fiscal Affairs and Sponsored Project Administration

KENTUCKY GEOLOGICAL SURVEY ADVISORY BOARD
Steve Cawood, Chairman, Pineville
Larry R. Finley, Henderson
Hugh B. Gabbard, Richmond
Kenneth Gibson, Madisonville
Wallace W. Hagan, Lexington
Phil M. Miles, Lexington
W. A. Mossbarger, Lexington
Henry A. Spalding, Hazard
Jacqueline Swigart, Louisville
Ralph N. Thomas, Owensboro
George H. Warren, Jr., Owensboro
David A. Zegeer, Lexington

KENTUCKY GEOLOGICAL SURVEY
Donald C. Haney, State Geologist and Director
John D. Kiefer, Assistant State Geologist for Administration
James C. Cobb, Assistant State Geologist for Research

ADMINISTRATIVE DIVISION

Personnel and Finance Section:
James L. Hamilton, Administrative Staff Officer II
Roger S. Banks, Account Clerk V

Clerical Section:
Jody L. Fox, Staff Assistant VII
Joyce Belcher, Staff Assistant VI
Juanita G. Smith, Staff Assistant V, Henderson Office

Publications Section:
Donald W. Hutcheson, Head
Margaret Luther Smath, Geologic Editor III
Terry D. Hounshell, Chief Cartographic Illustrator
Richard A. Smath, Geologist III, ESIC Coordinator
Michael L. Murphy, Principal Drafting Technician
Gwenda K. Rulo, Drafting Technician
William A. Briscoe, III, Publication Sales Supervisor
Kenneth G. Otis, Stores Worker
Shirley D. Dawson, Staff Assistant V

GEOLOGICAL DIVISION

Coal and Minerals Section:
Donald R. Chesnut, Jr., Acting Head
Garland R. Dever, Jr., Geologist VII
Cortland F. Eble, Geologist V
David A. Williams, Geologist V, Henderson Office
Warren H. Anderson, Geologist IV
Gerald A. Weisenfluh, Geologist IV
Stephen F. Greb, Geologist III
Robert E. Andrews, Geologist I
Margaret E. Reed, Data Entry Technician

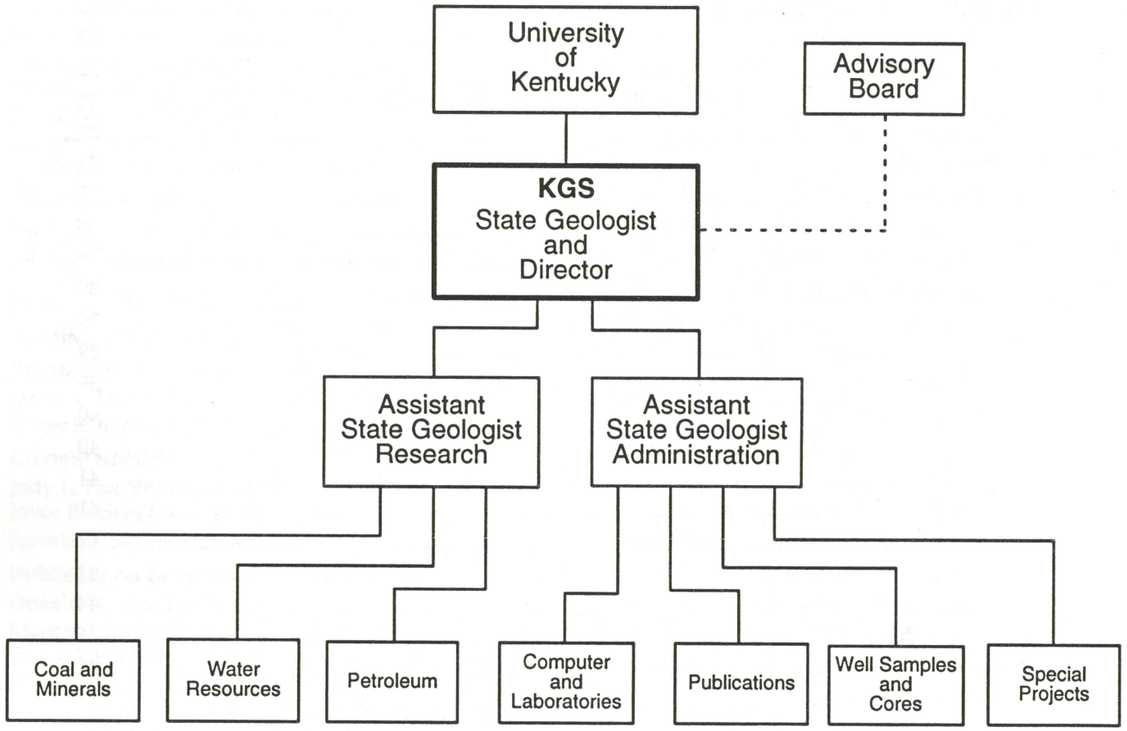
Petroleum and Stratigraphy Section:
James A. Drahovzal, Head
Terence Hamilton-Smith, Geologist V
Patrick J. Gooding, Geologist IV
David C. Harris, Geologist IV
Brandon C. Nuttall, Geologist IV
Matthew Humphreys, Geologist II
Gerald J. Kinsella, Geologist I
Thomas N. Sparks, Geologist I
Anna E. Watson, Geologist I
X. Mara Chen, Post-Doctoral Scholar
James B. Harris, Post-Doctoral Scholar
Robert R. Daniel, Laboratory Technician B
Jay C. Ramsey, Laboratory Assistant
Eugenia E. Kelley, Staff Assistant V
Frances A. Benson, Staff Assistant IV
Luanne Davis, Staff Assistant IV
Theola L. Evans, Staff Assistant IV
Kimberly B. Stroth, Staff Assistant IV

Water Resources Section:
James S. Dinger, Head
James A. Kipp, Geologist V
Daniel I. Carey, Hydrologist IV
James C. Currens, Geologist IV
David R. Wunsch, Geologist IV
Alex W. Fogle, Hydrologist III
Philip G. Conrad, Geologist II
O. Barton Davidson, Geologist II
Dwayne M. Keagy, Geologist II
Shelley A. Minns, Geologist II
Ed Fortner, Jr., Geological Technician
C. Douglas R. Graham, Geological Technician
Tim Montowski, Geological Technician
Kevin J. Wente, Geological Technician

Computer and Laboratory Services Section:
Steven J. Cordiviola, Head
Richard E. Sergeant, Geologist V
Joseph B. Dixon, Systems Programmer
Henry E. Francis, Associate Scientist
Steven R. Mock, Senior Laboratory Technician
Karen Cisla, Senior Research Analyst
Eric E. Lovins, Research Analyst
Mark F. Thompson, Research Analyst
Tammie J. Heazlit, Senior Laboratory Technician

CONTENTS

ORGANIZATION OF THE KENTUCKY GEOLOGICAL SURVEY



FOREWORD

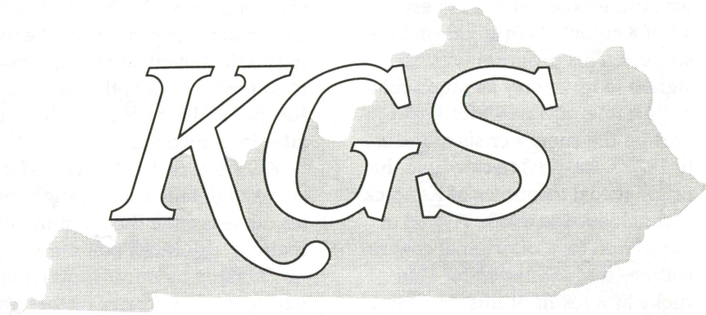
The Kentucky Geological Survey has conducted research on the mineral and water resources of Kentucky for the past 156 years. These efforts have resulted in topographic and geologic map coverage for Kentucky that has not been matched by any other state in the United States, and public data bases on energy, mineral, and water resources that are used by thousands of citizens, private industry, and government agencies each year. Virtually every sector of modern society requires information about the earth: its resources, hazards, and environments. Society's needs for geologic and resource information change, and therefore the job of characterizing Kentucky's geology and resources also changes. The Kentucky Geological Survey has continued to build its public data bases and perform basic research to satisfy the changing needs of the Commonwealth.

KGS provides technical advice to a large number of State and Federal agencies. In addition, the Survey places great emphasis on public-service activities. Members of the Survey staff are actively involved in special committees and public-service groups dealing with coal, water, oil and gas, industrial minerals, and geologic hazards. In particular, Dr. Donald C. Haney, State Geologist and Director of the Kentucky Geological Survey, is currently serving as past-president of the American Geological Institute, a federation of the 20 major geological and related professional associations that serve the earth sciences. In addition, Dr. Haney has been appointed to the Board on Earth Sciences and Resources of the National Research Council, which is the principal operating agency of the National Academy of Sciences. The Board on Earth Sciences and Resources coordinates the National Research Council's advice to the Federal government on earth-science issues, ranging from basic research, through application, to assistance in policy formulation. The Board is responsible for conducting studies and preparing reports on fundamental issues in the earth sciences and on the directions that disciplines of the earth sciences should be taking, as well as issues relating to the energy and mineral resources of the Nation. Dr. Haney will serve as a member of the board until the end of 1995.

The objective of this annual report is to provide a brief summary of the activities of the Kentucky Geological Survey during the past fiscal year (July 1, 1993–June 30, 1994).

RESEARCH ACTIVITIES

Basic research in geology and hydrology has formed the cornerstone of the Kentucky Geological Survey since its inception. The Kentucky Geological Survey maintains a diversified and comprehensive research program into the fields of coal geology, industrial and metallic minerals, oil and gas, and hydrology. In addition, a number of special projects are funded by grants or contracts. Projects in all of these areas of research are described in greater detail in the following sections.



Coal

Coal is Kentucky's leading mineral industry in terms of revenues generated and employment. Coal production was 174.3 million tons in 1992. During fiscal year 1992-93, coal produced in Kentucky had a value of more than $4 billion dollars. During the same period, the Kentucky coal industry generated $180 million in coal severance taxes. In the coal fields, coal mining accounts for most of the total industrial output. For example, a recent economic impact study of Pike County, Kentucky, indicated that coal mining accounted for 46 percent of the total industry output of that county. In the same study, 21 percent of the total employment of the county was in coal mining. Obviously, the future development of the coal industry in Kentucky will have a direct and significant bearing on the economic health of the State.

Part of the mission of the Kentucky Geological Survey is to assess the coal resources of Kentucky. In order to accomplish this mission, KGS conducts research in cooperation with the U.S. Geological Survey (USGS), the U.S. Bureau of Mines (USBM), and the U.S. Department of Energy (DOE). Beginning in the 1970's, a major effort was undertaken at KGS to estimate all of Kentucky's original coal resources. This program was designed to inventory as much coal as possible, and was motivated in part by the energy crisis of the early 1970's. Its goal to calculate the original coal resources of Kentucky was achieved in 1983. A total of 105 billion tons of original coal resources was estimated for Kentucky as a result of this program.

In the 1990's, the approach to coal-resource estimation shifted from an emphasis on original resources to an emphasis on the remaining coal resources and the restrictions to coal recoverability. This new approach was pioneered in Kentucky in cooperation with the U.S. Geological Survey and is called the Coal Availability Program. As a part of this new approach, in 1993 KGS, supported in part by the DOE–Energy Information Administration, calculated the Demonstrated Reserve Base (DRB) of the Eastern Kentucky Coal Field. This DRB is an estimate of the remaining resources that can be demonstrated, using information available to KGS. Results of this study are shown in the first row of the following table.

Demonstrated coal resources in eastern Kentucky by category (millions of tons).

Reserve Base	*Underground*	*Surface*	*Total*
KGS-DRB	2,815	10,085	12,900
Accessible	2,535	8,728	11,263
Recoverable	1,572	6,895	8,467

The ongoing Coal Availability Program is designed to measure the technological and land-use restrictions to the mining of coal. This project involves a series of highly detailed quadrangle studies scattered across both coal fields. Data from this project will be used to predict the effect of restrictions to mining across both coal fields. Results of the project are described later in more detail.

KGS is assisting the USBM in a series of detailed quadrangle studies that examine the amount of remaining resources that are actually recoverable by mining, given prevailing cost and price factors for coal. This recoverability project focuses on economic and engineering factors in coal mining. Results of the recoverability investigations will allow projections to be made for an entire coal field. Preliminary recoverability findings suggest that approximately 8 to 35 percent of the original resources are recoverable. Between 0 and 13 percent of the original resources are both economically recoverable and meet future compliance standards for sulfur content (1.2 pounds sulfur dioxide or 0.6 pound sulfur per million Btu). Results from these cooperative resource studies provide valuable information for predicting the future of coal in Kentucky.

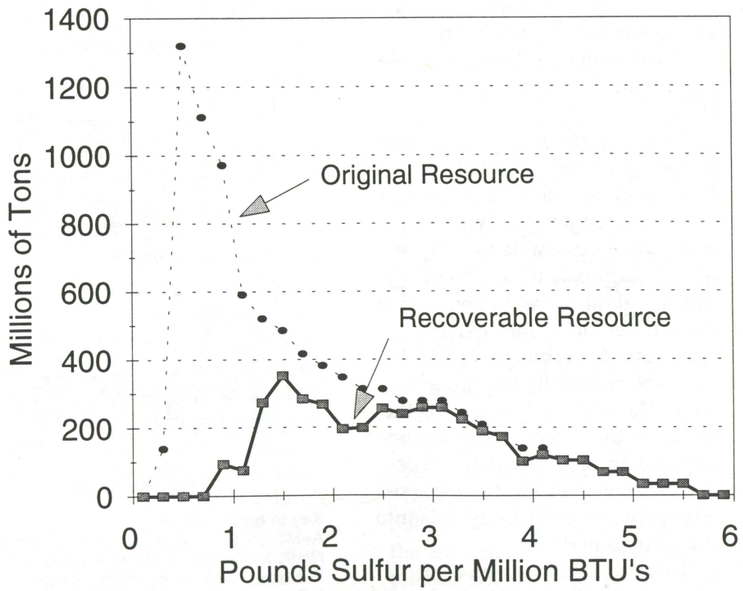
For the past 200 years, coal has been mined in Kentucky from coal beds near the surface ("above drainage" in industry terms). However, the coal industry is reaching a critical stage in its use of the resources. The preliminary results of the resource programs are shown in the preceding table, which illustrates reserve tonnages that can be demonstrated using data available to KGS. The recoverable reserve base for known deep-mineable coal is 1.6 billion tons, and known surface-mineable coal is 6.9 billion tons. However, the surface-mineable coal resource is calculated to a highwall height of 200 feet, a height that is physically possible to mine but not generally mined today. Environmental liabilities and economic factors restrict coal companies from surface mining previously mined benches. Therefore, previous mining to a highwall height of 80 feet essentially locks out a significant amount of coal situated between the two highwall heights. Accordingly, the actual recoverable reserves in the surface-mineable category are probably only a fraction of that shown in the table. At the present

rate of production (84 million tons for deep mines per year), eastern Kentucky has about 20 years of the demonstrated recoverable reserve base of deep-mineable coal to mine.

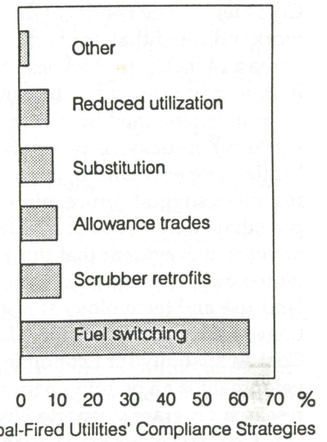
A similar study for the Western Kentucky Coal Field has not yet begun, but results are expected to be similar. However, significant resources of as yet unidentified coal may exist in the deeper subsurface. Data on these deeper coal-bearing rocks are largely lacking. In order to learn more about the deeper subsurface coal resources, KGS has an ongoing project to compile and analyze subsurface data (described below).

Future production beyond the next couple of decades will have to come from reserves that will be more difficult to find and develop. At present, we cannot demonstrate with existing data that future reserves of high-quality coal occur in Kentucky. The graph at bottom left shows the distribution of sulfur content in relation to demonstrated recoverable resources of underground-mineable coal in eastern Kentucky. The graph illustrates that significant recoverable resources of high-quality coal cannot be demonstrated with available data. Future mineable resources may occur below valley bottoms, but at this time few data exist on these deeper coal-bearing rocks. The Kentucky Geological Survey has several projects, described later, which attempt to locate and characterize the future recoverable coal resources of both coal fields in Kentucky.

The present market for Kentucky coal is controlled by the largest consumer, the electric utilities in the eastern United States, which purchase 77 percent of coal produced in Kentucky. In the past, utilities commonly made long-term contracts with coal producers. However, the utilities will probably adopt the practice of using short-term contracts and, consequently, the market will become oriented toward a highly competitive spot market. This agressive competition is expected to keep the price of coal low.



The Clean Air Act Amendment of 1990 is also changing the market for Kentucky coal. This amendment requires that utilities restrict their release of sulfur compounds into the air. As a result, utilities are adopting a variety of methods to control sulfur emissions. The graph at bottom right shows strategies the American utilities have planned to meet compliance standards (from Brian McLean, EPA, 1994). Approximately 63 percent of the utilities report they will switch to lower sulfur coals or to other fuels. However, as the graph below shows, significant amounts of low-sulfur coal cannot be demonstrated in Kentucky with our present data. In addition, the EPA in the near future may regulate certain hazardous trace elements in the emissions of coal-fired plants. Information on the quality of Kentucky coals, including sulfur content, Btu's, trace-element content, and washability, will be critical to coal users and coal producers in the very near future. The Kentucky Geological Survey has such a coal-quality data base and has initiated a project to collect information on washability and trace-element content of Kentucky coals. Coal-quality research conducted during the past year is described later.



Coal-Fired Utilities' Compliance Strategies

The projects described below are designed to answer questions about the future coal resources. These projects cover coal-resource assessment, coal-mining geology, and coal quality and petrography. Coal-related information generated by these projects is made available through the Kentucky Coal Resources Information System (KCRIS), which is one of the largest publicly available coal data bases in the United States. KCRIS contains descriptions of coal beds, coal-thickness measurements, coal-quality analyses, and borehole descriptions. Most of this information is in electronic form and is updated on a continual basis. In addition to the KCRIS data base, the Kentucky Geological Survey promotes technology transfer through workshops. Information is also made available to the public through publications.

Coal-Resource Assessment

AVAILABLE COAL RESOURCES IN EASTERN AND WESTERN KENTUCKY

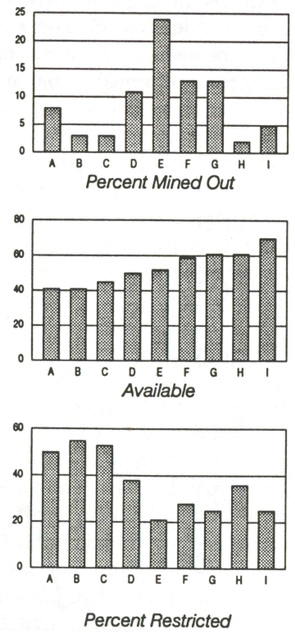
Gerald A. Weisenfluh, Robert E. Andrews, John K. Hiett, and Stephen F. Greb

In 1983, detailed coal-resource estimates were completed for the Eastern and Western Kentucky Coal Fields. The results of this work indicated that, for beds greater than 14 inches in thickness, 57 billion short tons and 38 billion short tons remained in eastern and western Kentucky, respectively. While these estimates of the total resources suggest future mining potential on the order of hundreds of years, it is evident that this potential may be greatly reduced if land-use and technological restrictions to mining are considered. Coal Availability for Economic Development is an ongoing national research program supported by the U.S. Geological Survey to quantify the kinds and magnitudes of restrictions to mining in order to plan the development of energy resources.

The use of geographic information systems now makes modifying the estimates of original resources practical, taking into account such diverse factors as mined-out areas, mine buffers, oil and gas wells, protected lands, cemeteries, roads, streams, and population centers. These revisions are being prepared for selected 7.5-minute quadrangles (58-square-mile map areas) and the results extrapolated to the remainder of the region. Studies for nine quadrangles within the Eastern Kentucky Coal Field have been completed. The results, summarized in the first graph to the right, show that the amount of coal mined out is generally less than 15 percent of the estimates of original resources. The amount of coal restricted from future mining varies between 26 and 58 percent, and the majority of these restricted resources are coal too thin to be mined by underground methods. According to follow-up studies by the U.S. Bureau of Mines, as little as 8 percent of the original resource is economically recoverable under current economic conditions.

The proportions of past and potential mining suggest that traditional resource estimates provide only a limited perspective of economically recoverable coal. Type of mining greatly affects how much coal can be recovered, and in eastern Kentucky, variation in thickness of overburden is both locally and regionally important as well. The relationships among the variables that affect mining are being studied in greater detail in order to serve as a basis for extrapolating the coal availability data into the entire coal field.

Two studies have been completed in the Western Kentucky Coal Field. This region differs substantially from eastern Kentucky in its coal-bed geology and mining methods. These differences are because there are fewer western Kentucky beds, although those that are mined are more laterally continuous. Moreover, the land surface has relatively low relief, which results in generally larger mine blocks than those in eastern Kentucky. One of the primary factors affecting coal availability is the interburden thickness between adjacent seams. In many cases, underground mining in one coal bed makes mining of adjacent beds impossible over substantial areas. In contrast, if these same coals are surface mineable, highly productive multi-seam mining is possible. Hence, as in eastern Kentucky, accurate characterization of overburden becomes an essential task for understanding the future of coal production in Kentucky.



Key to quadrangles:
A=Millard, B=Hoskinston, C=Middlesboro North, D=Booneville, E=Appalachia, F=Noble, G=Matewan, H=Handshoe, I=Boltsfork

DEEP COAL AND ENERGY RESOURCES OF THE WESTERN KENTUCKY COAL FIELD

David A. Williams and Stephen F. Greb

The Western Kentucky Coal Field continues to mature as a coal producing region. Historically, surface coal resources accounted for most of the coal mined here. However, as easily identified, low-cost, near-surface coal resources were mined, coal production progressed into the subsurface. Almost all of the active deep mines produce coal near the outcrop limit of the coal at relatively shallow depths along the margins of the basin. Yet a mine in the Springfield (W. Ky. No. 9) coal at depths of more than 1,000 feet in Union County has shown that coal can be economically mined from much deeper resources. To accurately assess the mineability of coals at depth in western Kentucky, data are needed on the thickness, quality, and lateral extent of coals in the subsurface.

In order for future decisions on the western Kentucky coal resource to be based on accurate information, the Kentucky Geological Survey continues to collect data on the deep coal resources of the coal field. Coal resources must first be identified using available subsurface data. After a potential resource has been identified, its extent must be mapped, and then mining conditions must be evaluated. Some coal beds, such as the Springfield coal, are easily identified and the mining conditions (with some exceptions) remain relatively constant at depth. Other coal beds, such as the Baker (W. Ky. No. 13) or the coals of the Tradewater Formation, are more variable in terms of thickness, quality, and mining conditions.

Detailed correlations of the Carbondale Formation in parts of Henderson, Union, and Webster Counties using coal core and downhole geophysical logs were finished this year and helped to unravel correlations of the Davis (W. Ky. No. 6) through Colchester coals. The Davis and DeKoven (W. Ky. No. 7) coals have both been mined at the surface, and the coals have different quality and thickness characteristics. Mapping and identification of potential deep resources in these coal beds depends on accurate correlation of the coals away from the surface. In the past their correlations across the area have been confusing, with some studies indicating the Davis, and others the Dekoven coal being most extensive in the subsurface. The new analysis of subsurface data indicates that the Dekoven coal is actually truncated by the Colchester coal to the east and the Davis coal is extensive across much of the region. These types of correlations are critical to understanding regional trends in coal quality and thickness.

Cross sections are currently being constructed to extend the correlation of coal-bearing rocks in Henderson, Union, and Webster Counties east and south into the outcrop regions along the edges of the coal field. These cross sections will connect to concurrent projects in Illinois and Indiana so that subsurface resource trends in all three states can be analyzed to better understand the deep coal resources of the Western Kentucky Coal Field.

GEOLOGIC ANALYSIS OF THE COAL-BEARING ROCKS OF WESTERN KENTUCKY FOR THE DEVELOPMENT OF COAL RESOURCES

Stephen F. Greb and David A. Williams

The Western Kentucky Coal Field produces 43 million tons of coal a year and has an estimated original resource of more than 41 billion tons. However, nearly all of the estimated resource is noncompliance, with average sulfur values well above 1.2 percent. Because 97.3 percent of western Kentucky coal is sold to electric utilities that are now required to cut sulfur emissions, there has been considerable debate about the future of mining in western Kentucky. That future is dependent on many factors, including the national economy, application of clean-air technology at electric power plants, trading emission allowances between utilities, new mining and coal-cleaning technology, new markets for western Kentucky coal, and future regulations. The consequences of these factors are far from certain, and coal production from the region remains unstable.

In order to anticipate future questions about western Kentucky coals, the Kentucky Geological Survey collects data on coals and coal-bearing strata across the coal field. This year the Kentucky Geological Survey collected 25 coal samples, made detailed descriptions of 30 coal-bearing cores representing 17,828 feet of measured section, and collected numerous coal-thickness measurements in the Western Kentucky Coal Field. Also, progress is being made on computerizing borehole data so that information on the deep-coal resources will be available in an electronic format.

Work resulting from a cooperative agreement between the geological surveys of Kentucky, Illinois, and Indiana to study the low- to moderate-sulfur coals in the upper part of the Tradewater Formation has begun in Kentucky after a year of work in Indiana. Known low-sulfur coals of the Brazil Formation in Indiana have been correlated southward into Kentucky to the Elm Lick coal zone, using subsurface well information. The cross sections show that the coals are cut out or thin in the subsurface across much of the area between present mines in Indiana

and Kentucky. Samples from active surface mines in Kentucky are being analyzed for comparison with the Indiana coals to determine possible trends in coal quality. It appears that sulfur and ash percentages are more variable in the Elm Lick zone than in its Brazil counterpart in Indiana, with sulfur values for the Elm Lick ranging from 1 to 5 percent across only a few kilometers. Also, the Elm Lick coal is bisected by numerous discontinuous shale and sandstone cutouts that decrease reserves in low-sulfur areas. Documentation of these features at the surface, where lateral changes in rock type, bedding, and thickness can be easily recorded, is critical for use in possible deep mining applications in the future, where lateral changes in coal and roof facies must be inferred from limited borehole data.

The Henderson field office had 129 visits and 184 phone calls for information about western Kentucky coals. The number of requests for information is encouraging, because future mining will depend on educated decisions based on accurate assessments of coal thickness and quality data.

GEOLOGIC ANALYSIS OF THE COAL-BEARING ROCKS OF THE EASTERN KENTUCKY COAL FIELD FOR THE DEVELOPMENT OF COAL RESOURCES

Stephen F. Greb

Accurate estimates of coal-bed resources, mineability constraints, coal-bed correlations, roof-hazard analysis and other applications of geologic data rely on detailed case studies and models of coal and coal-bearing rock at the surface, where lateral variability of thickness, quality, rock type, bedding, and other features can be accurately delineated. To this end, the Kentucky Geological Survey documents important geologic features for significant stratigraphic intervals at the surface so that information from these studies can be applied in the subsurface.

Recent correlations of the Lee Formation and the lower part of the Breathitt Formation have been tied to surface exposures of various parts of the stratigraphic interval to illustrate characteristics of coal beds in the lower part of the coal measures. These coal beds appear to have been largely controlled by the topography upon which they were deposited; coals thicken and split into paleotopographic depressions and thin toward inferred topographic highs, and characteristically undulate across relatively short distances.

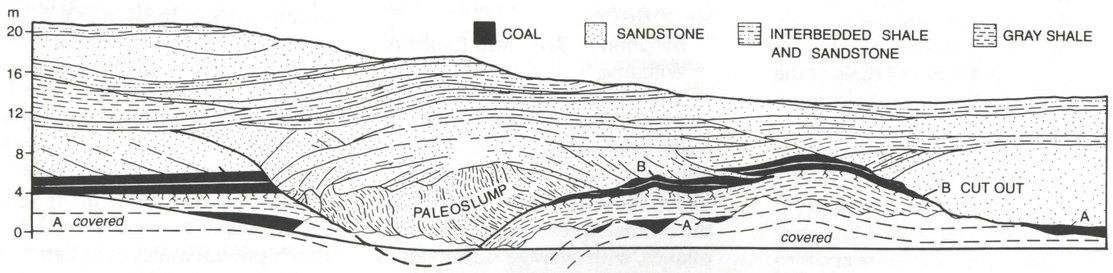
In a related study, comparisons of paleoslumps in road outcrops, surface-mine highwalls, and several deep mines indicate that these features may be more common then previously thought. Paleoslumps represent the prehistoric rotation or slumping of sediment on a slope, and are analogous to the slump of a stream bank into a stream. Where these ancient slump structures occur in the roof of an underground coal mine they create zones of high-angle, slickensided (highly polished and slick boundaries), and contorted beds that can be difficult or impossible to support. Many of the reported "faults" that cut out coal in coal mines are actually ancient slump structures. A manuscript is being prepared to show characteristic features of paleoslumps in the coal field.

COAL-BED METHANE AND DEEP COAL RESOURCES OF THE EASTERN KENTUCKY COAL FIELD

Stephen F. Greb

When attempting to locate deep (i.e., below drainage) coal resources, subsurface data such as borehole data from the coal industry and from oil and gas well records must be used. The purpose of this project is to collect, compile, and electronically archive these subsurface data so that they can be easily retrieved and used. This year we received a large collection of subsurface data, which greatly enhances the KGS data base and will be a benefit to those seeking coal information.

In order to use the subsurface data, we have recently acquired two software packages designed specifically to help interpret the subsurface logs. CoalMaster™ prints graphic lithologic columns from individual borehole records, giving KGS the capablility to provide a graphic log to the public rather than just a written record. The series of programs called Minex™ includes a very powerful geologic module. This module was obtained by the Kentucky Geological Survey and will be installed on one of the Sun workstations. It has the ability to graphically display a series of subsurface data, including geophysical logs, in a cross-section format. Identification and correlation of coal beds can be made on the screen and the data base can be updated simultaneously. Minex can also extract data from the borehole data base and construct coal-bed thickness maps, structure maps, and coal-quality maps.



Coal-Mining Geology

MINEABILITY OF KENTUCKY COALS

Stephen F. Greb and John K. Hiett

The geologic constraints on mineability of Kentucky coals are coal thickness, coal-bed continuity, coal quality, and roof and floor conditions. Often these factors are related. For example, where a coal bed splits and becomes discontinuous, its thickness decreases and its quality commonly deteriorates. Likewise, adverse roof conditions often occur near coal-bed discontinuities ("wants" in miners' terms) such as paleochannels ("rock faults" in miners' terms) in which the coal is completely replaced by the overlying roof material. The lateral distance across which any of these factors become detrimental to mining is quite variable. In order to better understand the effects of these variables on mining, a detailed study was begun on the Fire Clay coal bed in part of the Hazard Reserve District to demonstrate how coal-bed geology affects mining and recoverability.

To date more than 2,000 thickness measurements of the Fire Clay coal bed from a 15-quadrangle area of Breathitt, Knott, Perry, Leslie, and Letcher Counties have been collected and entered into the data base. Information on mining conditions and constraints to mining have been documented through interviews with mining personnel and visits to active mines in the area. All available information about past mining has been obtained from interviews with miners and analyzing more than 3,000 mine maps stored in the Mine-Map Information Center at the Kentucky Department of Mines and Minerals. Preliminary cross sections have also been constructed across the region using more than 500 boreholes, oil and gas well tests, in-mine measurements, and surface measurements of the Fire Clay coal zone.

All of the data collected to date will be manipulated in GRASS software so that original and remaining resources can be calculated for the area. Maps showing the total thickness of Fire Clay coal, thicknesses of individual benches of the coal, parting thickness, coal quality, and structural elevation on the base of the coal are being constructed. Trends of known rolls and cutouts are being mapped so that the width and internal characteristics of these features can be compared across the region. Detailed descriptions of other significant geologic features that have affected mining of the Fire Clay coal are also being assembled. All of the data will be compared and trends summarized so that a mineability model can be made for the Fire Clay coal that might be applicable to other coal beds.

Although the Fire Clay coal study is the most intensive part of the Mineability Project, the Kentucky Geological Survey also provides mineability information to operators of mines in other coal seams in the coal field. A manuscript is currently in review that summarizes known geologic constraints to mining in Kentucky and contains sections on various roof types (e.g., stackrock, paleochannels), isolated roof problems (e.g., kettlebottoms, coal balls), fractures, faults, and other features. The manuscript includes numerous photographs and illustrations of the geologic features from case studies made during the last 10 years by various members of the Kentucky Geological Survey, and will provide a valuable resource to the Kentucky mining industry.

Coal Quality and Petrography

COAL QUALITY CHARACTERISTICS OF MAJOR MINEABLE COAL BEDS IN KENTUCKY

Cortland F. Eble

Acid Deposition Control, enacted as Title IV of the Clean Air Act Amendments of 1990, will affect 261 electric utility units at 109 power plants in 21 states. In Kentucky, 17 units belonging to six utility companies will be affected. Phase 1, which will begin in 1995, will require coal-burning electric utilities to greatly reduce SO_2 emissions. To meet these new compliance standards, utilities in Kentucky and across the United States are switching to burning low-sulfur coal or are installing sulfur reduction devices (e.g., stack scrubbers, fluidized bed combusters) to help control sulfur emissions.

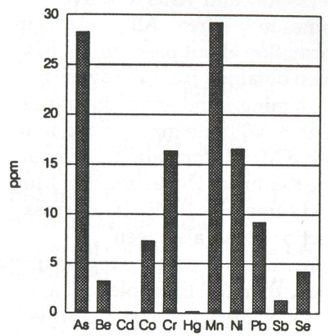
Although Acid Deposition Control has received a great deal of attention over the past several years, Title III of the Clean Air Act Amendments, "Hazardous Air Pollutants," is also an important, but probably less well known, regulation that will significantly affect the coal and electric utility industries. Of the 189 substances (mainly chemical compounds) cited in Title III that will require monitoring with the implementation of Phase 1 in 1995, 13 are elements that com-

monly occur in trace concentrations (generally parts per million) in coal. These 13 elements are: antimony, arsenic, beryllium, cadmium, chlorine, cobalt, chromium, lead, mercury, manganese, nickel, phosphorus, and selenium. Coal-burning electric utilities will be required to monitor levels of these elements in the coal feed stock they burn, and coal suppliers probably will be required to test for and report the levels of the elements in the coal they sell to power plants. As all 13 elements occur in trace concentrations, testing for them requires very specialized and sophisticated equipment, which translates into greatly increased analytical costs.

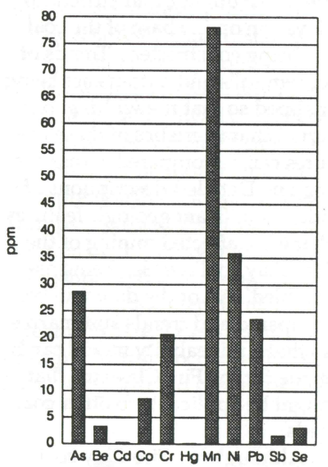
Trace elements in coal can be divided into two broad groups: (1) those that occur primarily as part of the coal molecule, such as beryllium and selenium, and (2) those that occur as part of the mineral fraction of coal. Examples of trace elements that occur as part of the mineral fraction are arsenic and lead. This distinction is important, since trace elements with inorganic affinities may be removed by physical coal-cleaning techniques; this is an important factor considering that the majority of coal mined in Kentucky is cleaned in preparation plants prior to shipment and use in power plants. However, some of the 13 elements listed above may occur in both the organic and inorganic fractions of coal, which complicates making washability predictions.

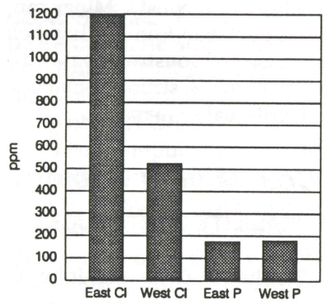
When coal is burned, many trace elements become incorporated with the incombustible portion of coal that either is collected as bottom ash or fly ash. Other elements are more volatile and largely escape with flue gases. Mercury and selenium are two examples of volatile elements.

The following graph shows the distribution of 11 trace elements in eastern Kentucky coal beds. Note



the relatively high concentrations of arsenic (As), chromium (Cr), manganese (Mn), and nickel (Ni), and the relatively low concentrations of beryllium (Be), cadmium (Cd), mercury (Hg), antimony (Sb), and selenium (Se). The next graph shows the distribution of these same elements in western Kentucky coals. Note the higher concentrations of manganese, nickel, and lead relative to eastern Kentucky coals. The third graph is a comparison of average chlorine (Cl) and phosphorus (P) contents in eastern and western Kentucky coals, showing that, on average, coals in the Eastern Kentucky Coal Field contain roughly twice as much chlorine as do coals from the Western Kentucky Coal Field. In contrast, phosphorus contents are essentially comparable.





The Kentucky Geological Survey continues to maintain and update a comprehensive, computerized coal-quality data base that gives measurements for trace elements for over 700 samples of Kentucky coal. Each year the Survey's coal analytical laboratories, which have been in operation since 1989, analyze several hundred coal samples. Presently, the lab routinely performs proximate (moisture, volatile matter, fixed carbon, and ash yield), ultimate (elemental carbon, nitrogen, hydrogen, and oxygen), total sulfur content, calorific value, ash fusion, and X-ray fluorescence analyses, and plans are being developed to expand the analytical capabilities to include testing for trace elements. This expansion will allow us to better serve citizens and industry in the Commonwealth.

Industrial and Metallic Minerals

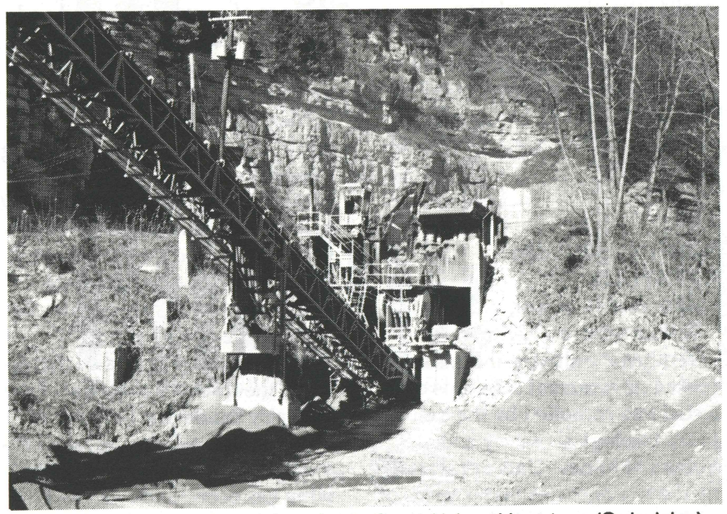
Industrial and metallic minerals provide essential materials for society by furnishing raw materials for agricultural, ceramic, chemical, construction, energy, metallurgical, and manufacturing industries. The Kentucky Geological Survey investigates the chemical composition, physical properties, geographic distribution, and geologic setting of industrial and metallic minerals in the State in order to provide information on potential resources for industry.

CHEMICAL CHARACTERIZATION OF CARBONATE ROCKS IN THE HIGH BRIDGE GROUP

Warren H. Anderson

The Clean Air Act Amendments of 1990 have created a demand for limestone and dolostone resources for use as chemical stone and sulfur sorbents in utility generating stations along the Ohio River. This project is a continuation of a regional study to determine chemical characteristics of the limestones and dolomites in the central Kentucky area for these uses.

A deep core drilled in Mason County, Kentucky, to investigate the High Bridge Group has been described and samples have been analyzed. A manuscript has been completed and is undergoing technical review. Chemical data were entered into a spreadsheet and incorporated into the manuscript. Preliminary results indicate that a thick high-calcium zone exists near the top of the Tyrone Limestone, and several high-carbonate zones exist in the Camp Nelson Formation.



Primary crusher outside entry to mine in Camp Nelson Limestone (Ordovician), Boonesborough, Madison County.

INDUSTRIAL AND METALLIC MINERAL RESOURCES AND MINERAL INDUSTRIES MAP OF KENTUCKY

Garland R. Dever, Jr., and Warren H. Anderson

A new mineral resources map of Kentucky is being compiled that will show the distribution of industrial and metallic minerals at a scale of 1:500,000. This map will show the distribution of limestone, sand and gravel, clays, and metallic and nonmetallic mineral deposits, as well as the locations of active mining and mineral operations. Distribution data will be taken from the new 1:500,000-scale state geologic map, and resource compilations will be taken from the 1:24,000-scale geologic quadrangle maps. Computerized files from the 1:500,000-scale state map will be utilized and modified for use in this report. Data on limestone resources for the western portion of the State and sand, gravel, and clay data for the Jackson Purchase area are currently being compiled.

LIMESTONE AND DOLOMITE RESOURCES FOR COAL-RELATED INDUSTRIES

Garland R. Dever, Jr.

Limestone and dolomite are used by coal producers and coal-burning industries in environmental-control measures to meet Federal and State standards for mine safety and reclamation, air quality, and water quality. The Kentucky Geological Survey is investigating the chemical and lithologic characteristics of the State's limestone and dolomite in order to determine

the availability of stone for the requirements of coal-related industries.

A 67-foot section of Camp Nelson Limestone (Upper Ordovician) exposed in the Boonesborough Mine, Madison County, was sampled at 1-foot intervals. The samples were analyzed to characterize the chemical quality of the deposit and to provide data for a statistical study of sampling procedures.

Average values for foot-by-foot analyses of low-silica and high-carbonate zones in the upper part of the Camp Nelson Limestone (Ordovician), Boonesborough Mine, Madison County.

	0–30 feet	44–67 feet
Thickness (ft.)	30	23
$CaCO_3$ + $MgCO_3$ (%)	93.17	96.03
$CaCO_3$ (%)	85.03	92.40
$MgCO_3$ (%)	8.14	3.62
SiO_2 (%)	2.48	1.75
Al_2O_3 (%)	0.73	0.42
Fe_2O_3 (%)	0.31	0.20
SO_3 (%)	0.14	0.12

The upper 30 feet and lower 23 feet of the 67-foot section are composed of low-silica stone, averaging 2.48 percent and 1.75 percent silica (SiO_2), respectively. The two intervals meet Federal silica specifications (not more than 4 percent free and combined silica) for rock dust used for explosion abatement in underground coal mines. The Boonesborough Mine currently supplies stone to a plant that produces rock dust for underground coal mines and agricultural limestone for surface-mine reclamation.

The lower 23 feet in the sampled section has an average calcium carbonate ($CaCO_3$) content of 92.40 percent and an average magnesium carbonate ($MgCO_3$) content of 3.62 percent. These average values meet the general specifications for limestone used in wet-scrubbing systems for flue-gas desulfurization at coal-burning plants.

SAND AND GRAVEL RESOURCES OF THE OHIO RIVER VALLEY

Warren H. Anderson

Deposits of Pleistocene sand and gravel, situated near several major metropolitan areas in northern Kentucky, are an important economic resource for construction. Knowledge of the geology of this resource will be an important component in effective land-use planning for the future economic development of the region. This project examines these important sand and gravel resources.

Project results indicate that three major glacial terrace deposits were formed in the northern Kentucky area: the pre-Illinoian, Illinoian, and Wisconsin. Of the three, the Wisconsin terraces are highest in gravel content, lowest in silt and clay content, and contain abundant limestone and dolostone clasts. This combination of characteristics makes the Wisconsin deposits attractive for mining.

All field, laboratory, and computer work has been completed, and a manuscript is in press. The final report should be completed as a Report of Investigations by the end of 1994.

NONFUEL MINERAL STATISTICS

Garland R. Dever, Jr.

Information on Kentucky's nonfuel mineral industry and mineral-related government actions is collected and compiled by the Kentucky Geological Survey and U.S. Bureau of Mines. Data are shared by the two agencies under terms of a Memorandum of Understanding and are published in the Bureau of Mines' "Annual Report," "Minerals Yearbook," "Mineral Industry Surveys," and commodity reports. KGS also uses the information to prepare reviews of industry activities and to answer public-service inquiries.

Based on estimated data compiled by the Bureau of Mines, the value of Kentucky's nonfuel mineral production in 1993 was about $416 million, an increase of about 1 percent over 1992. Crushed stone was the leading nonfuel mineral commodity, accounting for 60 percent of the State's nonfuel mineral value. Kentucky remained among the Nation's top producers of ball clay and lime, both of which increased in output during 1993. Other commodities produced in the State during 1993 included cement, common clays, and construction sand and gravel.

INDUSTRIAL MINERAL RESOURCES OF THE JACKSON PURCHASE REGION

Warren H. Anderson

The McNairy Sandstone is a fluvial-deltaic, micaceous sandstone that locally contains a high percentage of a pure silica sand and has been mined as a silica sand in Calloway County. The high percentage of muscovite in the McNairy Sandstone could also mean an additional byproduct for a mining operation. In some areas the McNairy Sandstone is a limonitic/hematitic sandstone that contains small amounts of titanium minerals such as rutile and ilmenite. This heavy-metal content may be as high as 2 to 3 percent.

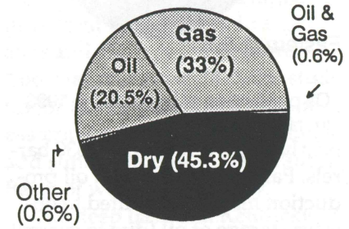
This project attempts to characterize the resource potential of the McNairy Sandstone in terms of heavy metals, silica sand, and other byproducts. Preliminary sampling has been conducted and some laboratory work has been initiated.

Petroleum and Stratigraphy

The research responsibility of the Petroleum and Stratigraphy Section is twofold: to conduct oil and gas research, and carry out research on the regional geology of the Commonwealth. Regional geologic research is vital to understanding the stratigraphic and structural framework of the State. Such knowledge is critical for understanding the character and distribution of energy and mineral resources, as well as the geologic aspects of environmental issues.

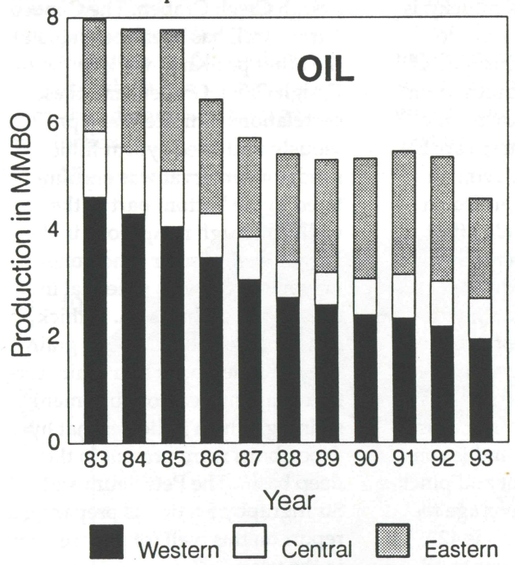
Natural gas and oil are important commodities for the Kentucky economy, ranking third and fourth, respectively, in value of natural resources produced in the State. In 1993 oil and gas production value was more than $276 million, bringing more than $12 million in severance taxes to the State. Nationally, the industry remains in a slump that extends back to 1986. Matching the national trend, gas production in Kentucky has increased over the past 5 years to be the highest since the late 1960's. Oil production, however, decreased during the year.

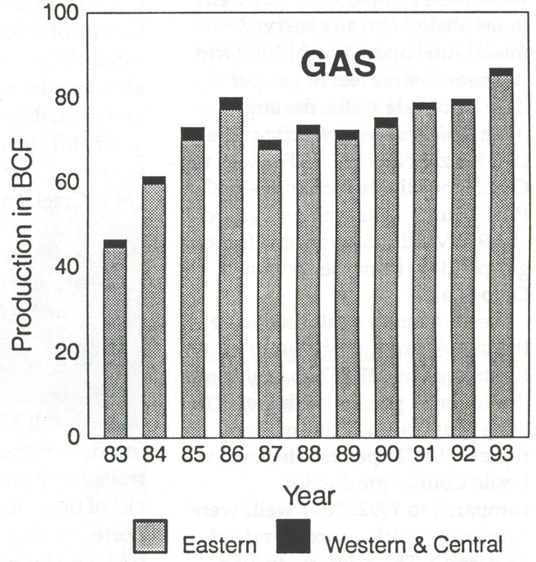
The activity summarized in this report is compiled on the basis of wells drilled, completed, and reported during the 1993 calendar year only. There were 497 wells reported drilled in Kentucky in 1993 and an overall success rate of 54 percent. A total of 77 exploratory wells were reported drilled, resulting in the discovery of five new fields and pools, four deeper pools, two shallower pools, and 12 extensions of existing pools. Total footage reported drilled during the year was 1.04 million feet, with an average well depth of 2,091 feet.



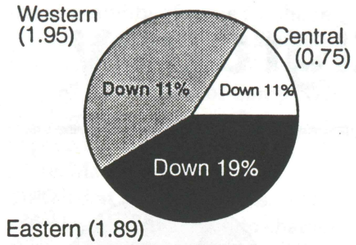
Well completions in Kentucky in 1993.

Compared to 1992, gas production increased 9 percent to 86.97 billion cubic feet (bcf). The 85.4 bcf produced in eastern Kentucky is the most gas ever produced in that region. Statewide, this year's gas production is the most since the years 1967 to 1969, when the Midland Pool of western Kentucky produced 15 to 20 bcf yearly. Oil production declined, however, by





Summaries of oil and gas production in Kentucky from 1983-93 reflect the National trend.



Oil production in Kentucky in 1993 in millions of barrels.

nearly 15 percent to 4,592,630 barrels. Part of the decline in oil production may be attributed to on-lease storage of oil (due to current low prices) and to the abandonment of stripper wells. Most of the State's oil production comes from stripper wells that in 1992 produced more than 5.3 million barrels (bbl) of oil. During the same year 293 stripper wells were abandoned.

In the Appalachian Basin of eastern Kentucky, 184 well completions were reported. Of these wells, 148 penetrated the Mississippian-Devonian Ohio Shale or deeper units, with a 95 percent success rate. A total of 116 wells were completed as gas wells in the shale, with an observed modal final open flow of 198 Mcfd (thousand cubic feet of gas per day). For shale wells, the largest open flow was reported from the J.W. Kinzer No. FH-176 Fee well in Carter coordinate section 13-N-87, Pike County. This well was gaged at 1.9 MMcfd (million cubic feet of gas per day) from the Devonian Ohio Shale.

Leslie County continued to be the top oil-producing county in Kentucky with 817,577 barrels produced, or 18 percent of the total State production. This amount represents a 24 percent decline in Leslie County production compared to 1992. Four wells were completed, with a success rate of 75 percent. The primary drilling target was the Mississippian Newman Limestone ("Big Lime"). An industry-funded project, the "Regional Subsurface Stratigraphy and Petrology of the Newman Limestone, Appalachian Basin, Eastern Kentucky," has been initiated at KGS to develop a better understanding of the geologic controls on Big Lime production.

Pike County was the most active county in eastern Kentucky with 87 wells reported. It was also the most prolific gas-producing county in the State with more than 31.5 bcf produced. The overall success rate was 98 percent; only one dry hole was reported.

The most active county in Kentucky was again Clinton County, near the axis of the Cincinnati Arch, with 128 wells reported. Clinton County oil production declined 11 percent to 363,503 bbl. "Application of GIS Techniques for Geologic Modelling of Fractured Carbonate Reservoirs in Clinton County, Kentucky" has been initiated at KGS to better understand the subsurface geology and controls on production.

Southwestern Edmonson County, west-central Kentucky, is the site of a new play. Wells located along and on either side of an unnamed surface fault shown on the Bristow and Brownsville geologic quadrangle maps are being completed in the Devonian Clear Creek and Silurian Dutch Creek Formations. While offset reaches a maximum of 80 feet in the Mississippian Hardinsburg Sandstone Formation at the surface, no offset is evident in either the pay zone or the Devonian New Albany Shale. The play appears to be the result of secondary porosity in a dolomitized zone and is controlled by development and pinchout of that zone. The average reported initial production is 42 b/d, and Edmonson County oil production has increased more than 450 percent.

In western Kentucky, oil production declined. Only 1.95 million barrels of oil were produced, representing an 11 percent decline. There were 51 reported completions. Daviess County was the most active county, with 21 wells reported. Hopkins County oil production increased nearly 8 percent to 206,597 barrels, one of only two counties in the top 10 oil-producing counties in the State to show an increase.

In late 1992 an important deep exploratory well was drilled by Conoco, Inc., in the Rough Creek Graben of western Kentucky. This well, the Conoco No. 1 Mark Turner, was drilled in McLean County (Carter coordinate section 21-M-29), and reached a total depth of 14,202 feet in Precambrian granite. The objective of this well was to test potential deep gas reservoirs in Cambrian Eau Claire Formation synrift sandstones. The well was plugged and abandoned, but has provided a wealth of information on the evolution and hydrocarbon potential of the Rough Creek Graben. The Conoco Turner well has been correlated to the other pre-Knox wells in the Rough Creek Graben, and these correlations indicate that a previously undrilled synrift lithic sandstone interval was encountered in the bottom part of the well. Although nonporous in the Turner well, similar sandstones may have reservoir potential in other parts of the basin. A thick zone of dolomitized oolitic grainstones in the upper Eau Claire section contains dead oil (bitumen) staining, which indicates that hydrocarbons were present in the deep basin. The Petroleum and Stratigraphy Section is preparing a report on this well for release later in the year.

Drilling and completion data for another deep exploratory well, the Conoco No. 1 Isaac Shain well, Grayson County (Carter coordinate section 2-L-36) are scheduled for release in late 1994. A third deep exploratory test by Conoco has been permitted in southern Illinois.

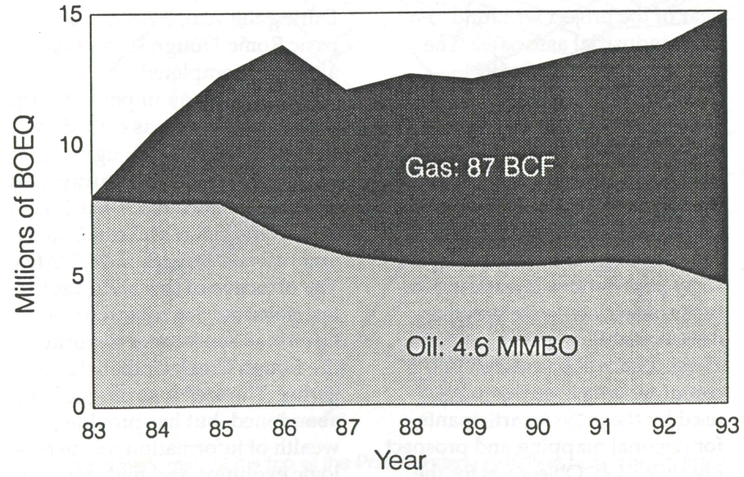
Hydrocarbons figure to be important bridging fuels well into the twenty-first century until renewable energy resources can be developed. Nationally, natural gas will play a significant role in the future domestic energy mix, because of its environmental acceptability, low cost, domestic availability, and importance to the emerging alternative fuels industry. One of the most significant future gas markets during the next decade will be electric-power generation. Strong industrial demand will propel United States gas consumption to 21 tcf (trillion cubic feet) a year by the year 2000, outpacing the growth rate of all other energy sources. The U.S. Department of Energy has recognized this potential and has increased gas-related research funding by more than 60 percent for fiscal year 1995. The U.S. Department of Energy has also developed "The Domestic Natural Gas and Oil Initiative," which focuses heavily on increased domestic natural gas production.

This past year was a pivotal year in that the value of natural gas production in the United States exceeded that of crude oil output for the first time in history. The historic reversal is due to several factors including the recent upward price trend, the record cold winter in much of the United States, and the newly revitalized, restructured gas industry that is now operating in an improved regulatory environment. Kentucky reflected this trend with increased gas production that outstripped the value of oil production statewide by a margin of more than 2.5 to 1. The State has large untapped natural-gas resources; with the proper incentives and support, careful planning and commitment, and pipeline availability, this sector of Kentucky's economy could show significant growth during the decade, providing the Commonwealth with a strong energy base, a vital industry, well-paying jobs, and increased oil and gas revenues, together with sustainable development.

Recovery of oil and gas from known domestic reservoirs is being recognized as an important source for the future domestic energy supply. Compiling oil and gas data bases and atlases is a vital first step in evaluating these resources. Such data will be useful to reservoir-characterization studies critical in the future development of exploration and production strategies. The Petroleum and Stratigraphy Section is continuing its current involvement in a gas atlas and Tertiary Oil Resources Information System (TORIS) studies for the Appalachian Basin in eastern Kentucky and is seeking to add similar studies for the Illinois Basin of western Kentucky.

The deep basins in Kentucky are potentially important gas provinces. Companies are examining recently available reflection seismic data for the Rome Trough and the Rough Creek Graben and discussing exploration strategies for natural gas production. The Petroleum and Stratigraphy Section is involved in an Illinois Basin Consortium study of seismic data for the Rough Creek Graben and is discussing possible future cooperative research projects in both basins with industry and academia.

Environmental concerns are increasingly important in Kentucky as well as the Nation. Subsurface geologic information is key to several of these issues, including earthquake risk, potential deep-



Kentucky 1983-93 oil and gas production on a barrels of oil equivalent (BOEQ) basis.

well waste disposal, ground-water pollution, and NORM (Naturally Occurring Radioactive Material) associated with oil and gas production. In cooperation with the Kentucky Cabinet of Human Resources, the Division of Oil and Gas, the Division of Water, Department for Environmental Protection, Kentucky Oil and Gas Association, and Kentucky Resources Council, the Kentucky Geological Survey helped organize a study of nine oil fields to assess the potential for NORM-related problems in the State.

The Petroleum and Stratigraphy Section is currently participating in the University of Kentucky seismic network to monitor earthquake activity in the State and, in particular, the New Madrid Earthquake Zone of western Kentucky. Seismic hazards for municipalities and public works in western Kentucky are being assessed.

The Petroleum and Stratigraphy Section continues to play an instrumental role in various consortia with other state geological surveys. We are continuing our association with the Illinois Basin Consortium, the Cincinnati Arch Consortium, and the Appalachian Oil and Natural Gas Research Consortium. In addition, we are cooperating with the U.S. Geological Survey in several research projects, and have joined with Clinton County and the Los Alamos National Laboratory in a study of the high-volume Ordovician reservoirs. And we are currently cooperating in a five-state consortium to seek funding from the U.S. Department of Energy to compile oil and gas atlases for the Illinois and Michigan Basins. In addition, we are discussing interstate cooperation in the U.S. Department of Energy-funded Petroleum Technology Transfer Council development projects in both the Illinois and Appalachian Basins.

The Petroleum and Stratigraphy Section performs research in six general areas: Basin Analysis, Regional Geology, Hydrocarbon Resources, Geophysics, Oil and Gas Data, and Drill Cuttings and Core Samples.

Basin Analysis

REGIONAL SUBSURFACE STRATIGRAPHY AND PETROLOGY OF THE NEWMAN LIMESTONE, APPALACHIAN BASIN, EASTERN KENTUCKY

David C. Harris and Thomas N. Sparks

The goal of this new project, a continuation of The Stratigraphy and Reservoir Sedimentology of Mississippian Carbonates in Kentucky (Appalachian Basin), is to provide the regional stratigraphic and petrologic data necessary for oil and gas companies to evaluate the hydrocarbon potential of the Newman Limestone (Big Lime) in eastern Kentucky. Increasing production from this interval in recent years is indicative of the future potential of the zone, but realization of this potential will require a consistent and accurate regional data set for interpretation. Efforts to secure funding for the project in 1993 were successful, and the first year of the project was funded by three industrial associates. The project began in early 1994.

The first year objectives include collecting stratigraphic-tops data for approximately 8,000 wells, and Big Lime porosity data for approximately 1,100 wells. The study wells were selected by computer from the more than 29,000 Big Lime penetrations in eastern Kentucky; selections were based on data availability, quality, and age. These data will be entered into a computer data base that will be used by the project participants for regional mapping and prospect identification. Objectives for the second year of the project include sedimentologic and diagenetic studies to aid in porosity prediction, but are contingent on continued funding.

A geologist was hired to work on the project in early 1994, and data collection is currently in progress. Fourteen regional cross sections using digitized well logs were constructed to assist with regional correlations. Formation tops data from eight major units and four subzones within the Big Lime are being collected. Porosity data will be collected for wells producing from the Big Lime that have a density log available. The first phase of this project will be completed in February 1995.

STRATIGRAPHY AND SEDIMENTOLOGY OF PRE-KNOX SEDIMENTARY ROCKS IN THE ROME AND ROUGH CREEK GRABENS

David C. Harris, David A. Williams, Warren H. Anderson, and James A. Drahovzal

The emphasis of this project has changed during the past several years and is currently focusing on the Rough Creek Graben and the recent deep wells that have been and continue to be drilled there. During the year, however, some basic Rome Trough studies have also been completed.

In late 1992, an important deep exploratory well was drilled by Conoco, Inc., in the Rough Creek Graben of western Kentucky. This well, the Conoco No. 1 Mark Turner, was drilled in McLean County, and reached a depth of 14,202 feet. The objective of this well was to test potential gas reservoirs in Cambrian sandstones deposited in the Rough Creek Graben during rifting. The well was plugged and abandoned, but has provided a wealth of information on the geologic evolution and hydrocarbon potential of the Rough Creek Graben.

Results from the Conoco Turner well were confidential for 1 year, but have now been released. A detailed description of samples for the entire well has been completed. Samples have been collected for source-rock analysis, which will be performed by the USGS. Initial well-log analysis has begun using digitized log data from Conoco. The Conoco well has been correlated to the other pre-Knox wells in the Rough Creek Graben, and these correlations reveal a previously undrilled, synrift lithic sandstone interval in the bottom of the well. Although nonporous in the Turner well, this zone may have reservoir potential in other parts of the basin. A thick zone of dolomitized oolitic grainstones in the upper pre-Knox section contains bitumen staining, which indicates hydrocarbons were present in the deep basin. Lithologic descriptions, source-rock analyses, and stratigraphic interpretations will be published in late 1994 in a KGS publication.

Results of the research on the pre-Knox section in the Turner well were presented to two industry groups and a State survey during 1994. Research will continue with description of samples from Conoco's second deep well in the Rough Creek Graben, the No. 1 Shain well in Grayson County. This well did not reach its target depth of 19,000 feet because of mechanical problems, but did penetrate approximately 4,750 feet of pre-Knox sediments.

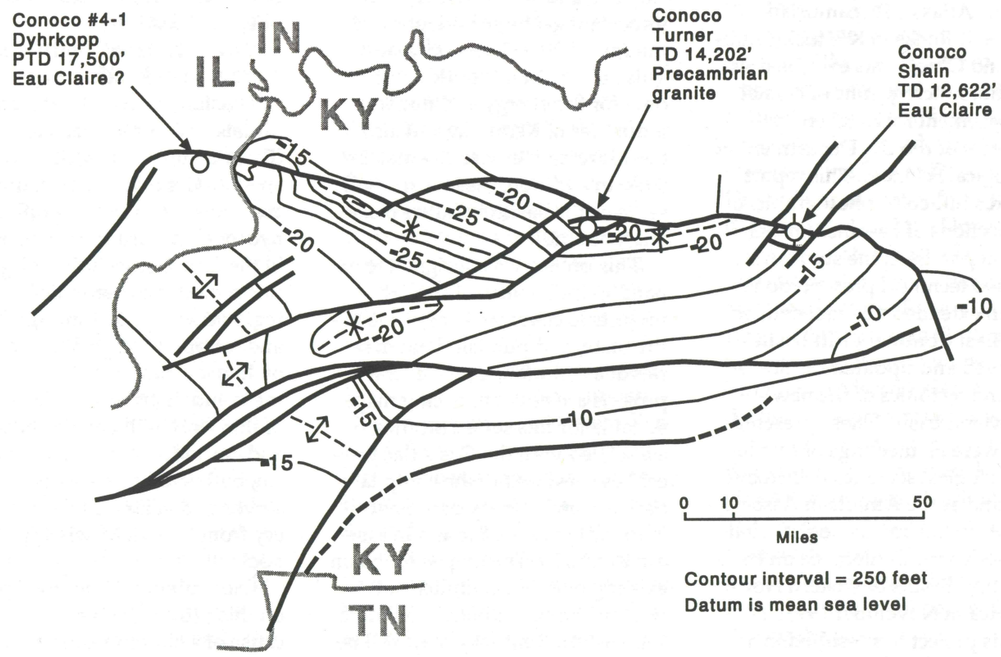
Interpretation of available seismic data has revealed the possible presence of fan-delta complexes in both the deep parts of the Rough Creek Graben and the Rome Trough. Such fan-delta deposits often are excellent reservoir facies. Based on this work, an exploration strategy that differs from the current approach in the Rough Creek Graben is proposed. Two technical presentations on the subject were given during the year—one at the Twenty-Fifth Annual Appalachian Geology Symposium in March 1994 and one at the Annual Meeting of the American Association of Petroleum Geologists in June 1994.

A preliminary top-of-basement map was also completed for eastern Kentucky in association with this project.

REGIONAL GEOLOGY OF THE KENTUCKY–OHIO TROUGH

David C. Harris and James A. Drahovzal

This research has involved geological and geophysical delinea-



Preliminary map of the top of the Precambrian crystalline basement in the Rough Creek Graben, western Kentucky.

tion of the East Continent Rift Basin, a recently discovered Precambrian sedimentary basin located in north-central Kentucky and adjacent parts of western Ohio and eastern Indiana. Efforts during the year primarily involved technology transfer; two papers were submitted for publication by KGS, an open-file report was completed, and two technical talks were presented. A manuscript entitled "Sedimentary Petrology and Hydrocarbon Potential of the Precambrian Middle Run Formation in Kentucky and Adjacent Parts of Ohio and Indiana" contains all petrologic data on the Middle Run Formation and interpretations resulting from the project. The manuscript, "Petrology and Geochemistry of Some Precambrian Mafic Rocks, Kentucky and Indiana," discusses the origin and tectonic significance of basalts associated with the Middle Run Formation. Both these papers are in the final review process. The open-file report, "Petrographic Atlas of Precambrian Basement Rocks in Kentucky, Indiana, and Ohio," was compiled using photomicrographs of crystalline basement rocks taken by members of the UK Department of Geological Sciences. This report features full-color photographs of thin sections of basement rocks from key wells in the study area. The two technical presentations and an extended abstract entitled "The East Continent Rift Basin" reviewed and updated the structure and tectonics of the newly discovered basin. These presentations were at meetings of two local geological societies in October 1993 and at the American Association of Petroleum Geologists Hedberg Research Conference on Basement and Basins of Eastern North America in November 1993.

This project has resulted in a major re-interpretation of the deep basement geology in central Kentucky. A complex sedimentary rift basin is now known to exist where previously only granites and rhyolites were thought to occur. No economic mineral accumulations have yet been found, but a large area remains untested, and both minerals and petroleum are known from similar-age basins in the Midcontinent. Reactivation of faults associated with the East Continent Rift Basin affected parts of the overlying Paleozoic sedimentary section, and may have influenced the distribution of oil, gas, or economic minerals in younger rocks. Research related to this project will continue as new data and funding are obtained.

REGIONAL SUBSURFACE MAPS IN KENTUCKY

David C. Harris, James A. Drahovzal, and Martin C. Noger

The goal of this research is to produce a series of regional facies, isopach, and structure maps for important geologic horizons and intervals of the Commonwealth. This information is critical not only for the energy and mineral industries of Kentucky, but also for addressing environmental issues. In addition, these maps will serve as the basis for future basin-analysis studies.

This project was designed to expand maps resulting from other projects to cover parts of or the entire State, and publish them in series at a common scale. Several projects are now producing maps suitable for this series. Studies associated with the Gas Atlas project have resulted in the compilation of a preliminary basement map for the Rome Trough in eastern Kentucky. The map is based on existing deep-well, limited seismic, and some potential field data. The eastern Kentucky map will be published later in 1994. Recent studies in central and western Kentucky have resulted in only very generalized basement maps, and large data gaps exist. Recent acquisition of some key seismic lines, especially in the vicinity of the Rough Creek Graben, will provide more information that will be useful in the eventual production of a Statewide basement map. Such a map will have implications for future oil and gas exploration in Kentucky.

A pre-Middle Devonian subcrop map for the Commonwealth continues to be compiled as part of the Silurian–Devonian Corniferous project. This map will document the distribution of formations below the pre-Chattanooga/Ohio/New Albany Shale unconformity. Many of these formations are important oil-producing horizons in Kentucky.

STRATIGRAPHY AND RESERVOIR SEDIMENTOLOGY OF MISSISSIPPIAN CARBONATES IN KENTUCKY (ILLINOIS BASIN)

David C. Harris and Terence Hamilton-Smith

Mississippian carbonates in the Illinois Basin of western Kentucky (Fort Payne, Warsaw, St. Louis, and Ste. Genevieve Formations) are some of the most significant hydrocarbon-producing intervals in the Commonwealth. The goal of this project is to better define the regional subsurface stratigraphy and interpret the geologic controls on hydrocarbon reservoir development and distribution. The results of this work will benefit the oil and gas industry in the Illinois Basin, both in discovering new reserves and in increasing oil recovery from known Mississippian pools.

Only minor activity took place on this project during the year because of a shift in research emphasis to Mississippian carbonate reservoirs of the Appalachian Basin (*see* Newman Limestone project, above). One project member attended a field seminar on the Fort Payne Formation (Ullin Limestone) in southern Illinois and western Kentucky conducted by the Illinois State Geological Survey.

DEEP STRUCTURAL FRAMEWORK OF THE WABASH VALLEY FAULT SYSTEM AND ITS RELATION TO THE NEW MADRID SEISMIC ZONE

James A. Drahovzal

The relationship of the Wabash Valley Fault System and its seismicity to the New Madrid Seismic Zone farther south is currently not understood. An understanding of the structural geology and tectonic history of the deeper part of the Illinois Basin in western Kentucky is critical for studies of earthquake mechanisms and hazards in western Kentucky.

This project is Phase I of a proposed ongoing project with the Illinois Basin Consortium sponsored by the U.S. Geological Survey's Earthquake Hazards Reduction Program. Phase I is designed to assess the reflection seismic data available for the area and acquire as many data as possible. During the year, consortium members met with various oil- and gas-industry and seismic-acquisition representatives to review available seismic surveys of the Illinois Basin. As a result of these discussions, several seismic data sets were acquired. These include a large set of data for parts of central and western Kentucky and southern Illinois from Chevron USA Production Company, a data set from Union Pacific for the far western part of Kentucky, a data set from Texas Gas Transmission Company for the eastern part of the Rough Creek Graben, and small data sets from several other companies for parts of western Kentucky. Further acquisition activities are under way with several other companies, and digital-tape data are currently being requested for critical parts of the data sets.

Interpretation work on the seismic data sets provided by the U.S. Geological Survey was completed through individual work and several workshop sessions with the Illinois Basin Consortium and U.S. Geological Survey geologists. The results of these interpretations will be presented at a joint Illinois Basin Consortium-U.S. Geological Survey workshop in September 1994.

Because of the ongoing nature of the negotiations for additional seismic data, Phase I of the project has been extended.

Regional Geology

GEOLOGY ALONG KENTUCKY HIGHWAYS

Donald C. Haney and Martin C. Noger

The construction of highways in Kentucky has resulted in roadcuts that display important geologic features. Many prominent geologic features are also exposed only short distances from the highways. Numerous inquiries about these features are received by the Kentucky Geological Survey. Reports about the geology along Kentucky's major interstate highways, designed for professionals and the public at large, will fill a definite need.

Two reports, one on Interstate Highway 64 and one on Interstate Highway 24 and the Western Kentucky Parkway, were completed during the year and turned into the Publications Section for drafting and editing. The report on the Cumberland and Daniel Boone Parkways was initiated, and maps have been reduced for future field work. Future plans call for a similar report for the Alexandria-Ashland (AA) Highway.

SUBSURFACE STRATIGRAPHY AND RESERVOIR GEOLOGY OF THE SILURIAN-DEVONIAN CORNIFEROUS OF KENTUCKY

Joseph F. Meglen and Martin C. Noger

More than 60 percent of the hydrocarbons produced in Kentucky have come from the Silurian–Devonian Corniferous interval. Most of the oil and gas production is apparently associated with trapping along an erosional unconformity on the flanks of the Cincinnati Arch. The Corniferous holds the potential of being an important hydrocarbon-producing interval in the deeper parts of the Appalachian and Illinois Basins. The details of the Corniferous stratigraphy are critical in understanding its petroleum geology. In the past several years, additional well data have become available. These new data need to be integrated into an updated synthesis of the geology in order to develop successful hydrocarbon exploration models for the deeper areas.

During the year, several studies related to the Gas Atlas Project were completed that also related to the objectives of this project. These studies include draft manuscripts on the Lower Devonian–Upper Silurian unconformity (Corniferous) and the Upper Silurian Lockport–Big Six plays. Technical presentations on these plays were made at the Twenty-Fifth Annual Appalachian Geology Symposium in Morgantown, West Virginia, in March 1994. The final drafts of the presentations will be completed by mid-year and published as part of the Appalachian Gas Atlas next year. Current plans call for KGS publication of these manuscripts as well. A Corniferous project proposal for local-industry funding will be developed during the year.

These associated studies will aid the petroleum industry in for-

mulating a development and exploration strategy for the potentially productive rocks of the Silurian–Devonian carbonate interval in Kentucky by providing maps and interpretations on local and regional bases. These studies will also provide information that should encourage secondary and tertiary oil recovery projects.

REGIONAL STRUCTURAL CROSS SECTIONS, ILLINOIS BASIN, WESTERN KENTUCKY

Martin C. Noger and James A. Drahovzal

This project to compile structural cross sections continues in cooperation with the Illinois Basin Consortium (IBC). The Illinois Basin, which covers parts of western Kentucky, southwestern Indiana, and southern Illinois, is a sedimentary, interior cratonic sag basin that has produced some 4 billion barrels of oil from its shallow parts. The potential exists for large accumulations of hydrocarbons in deeper pre-Upper Mississippian strata. Construction of a network of structural cross sections from available data will provide an understanding of the regional structural geology, stratigraphy, and evolution of the basin and illustrate known and potential hydrocarbon sources, traps, reservoirs, and seals. The cross sections, in addition, provide a geologic framework for future geologic and mineral-resource and environmental studies.

Preliminary cross sections in the basin are currently being reviewed. The compilation of the Kentucky portion of the west–east and north–south cross sections has been delayed until data from Conoco for the test in Grayson County are available for incorporation in the sections.

Preliminary blackline copies of the printed cross sections are available from each of the member surveys. The IBC will publish the final editions of the cross sections in color.

TAR SANDS OF WESTERN KENTUCKY

Terence Hamilton-Smith

Through this study, industry's interest in tar sands continues to be monitored and stimulated. The in-place oil-resource potential of subsurface and surface tar-sand deposits in western Kentucky is calculated to be 3.4 billion barrels. Since 1980, the Survey has coordinated the program of the Tar Sands/Heavy Oil sessions of the Eastern Oil Shale Symposium, which meets annually in Lexington, Kentucky. The 1993 meeting was the last of this series, but the Petroleum and Stratigraphy Section will continue to monitor activity in this area.

This project is designed to keep the Survey up to date with industry activity associated with the tar-sand deposits of western Kentucky. Maintaining data bases ensures that necessary information will be accessible when economic conditions warrant commercial development of tar-sand resources.

Hydrocarbon Resources

NORM (NATURALLY OCCURRING RADIOACTIVE MATERIALS) EVALUATION IN THE OIL FIELDS OF KENTUCKY

Terence Hamilton-Smith, Brandon C. Nuttall, and James A. Drahovzal

This new project was initiated as a result of NORM (Naturally Occurring Radioactive Materials) contamination associated with the Martha oil field in eastern Kentucky and in direct response to a call from the Kentucky Cabinet for Human Resources for assistance. The Petroleum and Stratigraphy Section took an early lead by describing the pertinent available data bases, providing pertinent technical literature, listing the names and locations of all oil and gas pools in the State, and suggesting the design for a study to be undertaken by an interdisciplinary technical group. The technical group, which includes representatives of the Kentucky Geological Survey, the Department for Environmental Protection (Water and Superfund), the Division of Oil and Gas, and the Kentucky Oil and Gas Association, was formed under the leadership of the Radiation Branch of the Department for Health Services. This committee has met repeatedly to evaluate the potential NORM hazard in the oil and gas fields of Kentucky.

Available data suggest that NORM contamination in the petroleum industry of Kentucky is associated specifically with radium-bearing scale deposited in pipes, facilities, and pits resulting from brine production associated with oil, including both primary water production and waterflood stimulation. Gas and oil production without associated water is not expected to result in a NORM hazard. The committee has selected nine oil fields in Kentucky, based on age, size, producing reservoirs, associated water production, waterflood stimulation practices, and proximity to known radioactive formations, for initial investigation.

Field investigation consists of the measurement of both background radioactivity and radioactivity immediately outside oil-field wellheads and tank batteries, and assumes radioactivity consists of gamma emissions of radium-226. The Taffy Field in Ohio County of western Kentucky was the first field selected for investigation. Field work has been completed, resulting in abundant data, which are currently being compiled and analyzed.

Evaluation of the results of all nine field investigations will provide a sound technical basis for the subsequent formulation of NORM regulations for Kentucky.

GAS RESERVOIR CHARACTER OF DEVONIAN SHALES OF KENTUCKY

Terence Hamilton-Smith

Devonian shales, containing the largest natural gas reserves in Kentucky, are concentrated mainly in the giant Big Sandy Field of eastern Kentucky and western West Virginia. Significant shale gas exploration potential also exists elsewhere in Kentucky, particularly in the New Albany Shale of the western part of the State. Shale gas is contained in a unique fractured reservoir, which has resisted attempts at evaluation and commercial development with traditional methods.

"Gas Exploration in the Devonian Shales of Kentucky" was published by the KGS as Bulletin 4 in late 1993. A reservoir study of New Albany Shale gas production in the Shrewsbury Consolidated Field in Grayson, Butler, and Edmonson Counties is continuing; recent preliminary results were presented at a professional meeting in Owensboro. Completion of this field study is anticipated for 1994, with publication of the results by the KGS to follow in 1995.

APPLICATION OF GIS TECHNIQUES FOR GEOLOGIC MODELLING OF FRACTURED CARBONATE RESERVOIRS IN CLINTON COUNTY, KENTUCKY

X. Mara Chen, Terence Hamilton-Smith, and Brandon C. Nuttall

Since the discovery of a high-volume oil well in Clinton County in 1990, a "mini-boom" of drilling activity has occurred in that area. In response to regional and national interest, a cooperative research project with the Los Alamos National Laboratory (LANL) was proposed and initiated.

Nearly 4,000 wells have been drilled in Clinton County, and most of the recent oil production has been from fractured Ordovician carbonates of the High Bridge Group and uppermost Knox Group. However, despite the many wells drilled in Clinton County, the nature and orientation of the subsurface fracture system is not well known, and the ratio of successful wells to total wells drilled is low. Since early 1993, LANL has obtained microseismic data. Mapping of the event locations has shown distinct trends, interpreted by LANL as mobile subsurface fracture zones.

The objective of this project is to take an integrated approach to develop a geologic model for fractured carbonate reservoirs in the Clinton County area by combining the microseismic data, geologic data, remote-sensing data, and geophysical data using geographic information system (GIS) techniques. Results of this project are important not only to local oil and gas exploration, but also to other fractured oil and gas reservoir exploration studies in other regions.

The proposed work is divided into three stages. The first stage will focus on developing a digital GIS data base for Clinton Count that will include microseismic-event locations, well locations, digital-terrain, geologic, and geophysical data. The second stage will integrate the data layers to determine the correlation of microseismic event trends with other types of available data. Finally, in the third stage, a conceptual model of fractured carbonate reservoir occurrences will be proposed, which will be characterized by available geologic and geophysical data that can be readily used in hydrocarbon exploration.

To date a digital data base for this project has been partially established. The present data base consists of the microseismic observation data, including three-component observation data from both single- and two-well sets, digital terrain data, nearly 4,000 oil and gas well locations, drainage network data, road network data, 7.5-minute-quadrangle boundaries, and Carter coordinate index data. Some preliminary oil and gas data manipulation, three-dimensional modelling of the microseismic data and DEM data, has been carried out.

GAS POTENTIAL OF THE NEW ALBANY SHALE, ILLINOIS BASIN, WESTERN KENTUCKY

Terence Hamilton-Smith, Brandon C. Nuttall, and James A. Drahovzal

The goal of this project is to stimulate future production of natural gas from the New Albany Shale in the Illinois Basin of western Kentucky, southwestern Indiana, and southern Illinois. This project has been carried out by the Illinois Basin Consortium, composed of the Kentucky, Illinois, and Indiana geological surveys. The project has been funded by the individual geological surveys and by the Gas Research Institute. The final report has been written and will be published shortly by the Indiana Geological Survey on behalf of the Gas Research Institute and the Illinois Basin Consortium as Illinois Basin Studies 2.

CARBONIFEROUS OIL FIELDS OF KENTUCKY (ILLINOIS BASIN)

Terence Hamilton-Smith and David C. Harris

The Carboniferous beds of western Kentucky contain the largest oil reserves of the State. Daviess and Union Counties were

two of the 10 leading counties in the Illinois Basin in 1992 in terms of new wells drilled, accounting for 15 of the 86 new oil-well completions drilled in western Kentucky.

Research in this project will focus on reservoir evaluation using geophysical logs, supplemented by available core, test, and production information. The results of this research will benefit industry and government by providing an objective basis for the accurate assessment of reserves, as well as improving procedures for the more cost-effective development of the resource.

A reservoir evaluation of the Antioch Field of Hopkins County is in progress, using proprietary data provided by both Ashland Exploration and Har-Ken Oil Company. TERRASTATION log analysis and mapping software installed on a Sun workstation at KGS is being used for the analysis. This field study will be completed in 1994, and will result in a subsequent publication by the KGS.

Agreement has also been reached with Har-Ken Oil Company to conduct a reservoir evaluation of the New Cypress Northeast Field in Muhlenberg County. Work to date consists of preparation of a data base and collection of cores. This field study will also result in a publication by the KGS.

RESERVOIRS OF THE CINCINNATI ARCH, CENTRAL KENTUCKY

Terence Hamilton-Smith, David C. Harris, and Brandon C. Nuttall

Upper Ordovician oil reservoirs in south-central Kentucky continue to attract national attention because of continuing high-volume production in southern Clinton County. Deepening of an abandoned well in 1990 resulted in record-setting initial production for the region of 3,500 barrels of oil per day from fractured limestones of the High Bridge Group. Additional high-volume wells drilled in the vicinity of the discovery well established the existence of a large and productive reservoir, but of uncertain character and distribution. A second new field discovery in the High Bridge Group in northern Clinton County has been extended by the drilling of several successful development wells.

This project has been initiated to help reduce exploration risk by improving the ability to predict the distribution of major tectonic fracture systems responsible for high-volume production. In late 1993 KGS was awarded a contract by Los Alamos National Laboratory to provide geological support for a microseismic research project in Clinton County, which has the potential of imaging the reservoir fracture system. This project is described in more detail above.

PETROLEUM GEOCHEMISTRY AND SOURCE-ROCK EVALUATION OF HYDROCARBON RESERVOIRS IN KENTUCKY

Patrick J. Gooding

Hydrocarbons in Kentucky are produced from many stratigraphic horizons in a variety of rock types ranging in age from Early Cambrian to Early Pennsylvanian. The purpose of this study is to determine source-rock potential, crude-oil characteristics, and oil source-rock correlations by utilizing geochemical analysis, and to investigate the influence of geologic structures and tectonics on the maturation, migration, and accumulation of hydrocarbons in Kentucky.

KGS is currently compiling the geochemical analyses of oils and source-rock evaluations for public release. The interpretation of these data is the subject of a dissertation being completed in the University of Kentucky Department of Geological Sciences.

Geophysics

OPERATION OF THE KENTUCKY SEISMIC AND STRONG MOTION NETWORKS

James B. Harris

Operation of the Kentucky Seismic Network began in late 1980 following the 5.2 $m_{b,Lg}$ July 27, 1980, Sharpsburg, Kentucky, earthquake. The network is designed to monitor seismicity in and around the State, and has produced over 1,000 recordings of regional earthquakes since it began operation. The network presently consists of 11 borehole-mounted, short-period seismometers deployed across the State from Grayson, in the east, to Clinton, in the west. The seismic data are transmitted to the UK campus via the state KEWS (Kentucky Early Warning System) microwave network. Continuous drum recordings of seismic activity are used for visual analysis, and the data are digitized and stored on a computer for advanced processing and display.

The Kentucky Strong Motion Network consists of five surface-mounted, three-component accelerographs, and two vertical (surface and borehole instruments) accelerometer arrays, located in western Kentucky and northwestern Tennessee, in the vicinity of the New Madrid Seismic Zone. The data are transmitted by telephone modem links between the individual stations and the Seismic Lab at UK. The strong-motion network is designed to investigate the effects of thick sequences of unconsolidated sediments associated with the lower Ohio River Valley, the central Mississippi River Valley, and the Mississippi Embayment on earthquake ground motions, and provide engineers with high-quality data that can be used in the design and construction of safer structures. Since it began operation in 1990, the Kentucky Strong Motion Network has provided over 25 digital recordings, and the data are compiled in a KGS open-file report.

SEISMIC HAZARD ANALYSIS IN KENTUCKY

James B. Harris

Amplification of earthquake ground motions by near-surface geologic conditions has been recognized as a major cause of damage in areas underlain by deep, poorly consolidated sediments. Several Kentucky communities along the lower Ohio River are at risk to severe earthquake damage because of their foundation on deep alluvial material and their proximity to the New Madrid and Wabash Valley Seismic Zones.

In order to estimate the potential for soil-column amplification, a microzonation of the Paducah area has been completed, and a similar study in the Henderson area is nearing completion. In both studies, surface seismic (refraction and reflection) methods, integrated with available geotechnical data, were used to characterize site conditions and determine material properties.

An associated study to determine site conditions at central United States strong motion stations operated by the Seismic Lab at UK and the Lamont-Doherty Earth Observatory at Columbia University has been completed, and a follow-up study designed to compare various techniques for measuring soil properties is underway. This research is important in defining the effects of the soil column on earthquake records, and in correcting the records for site effects so they can be used in site-response modelling studies at other locations. Other ongoing research projects include regional depth-to-bedrock and multi-dimensional seismic modelling studies of the Jackson Purchase area, and seismic hazard analysis of bridges in Kentucky.

INVESTIGATIONS OF SHALLOW STRUCTURAL DEFORMATION IN THE CENTRAL NEW MADRID SEISMIC ZONE

James B. Harris

The style and extent of deformation in shallow, unconsolidated sediments of Quaternary age, and the relationship between near-surface structure and deeper faults is unknown throughout much of the New Madrid Seismic Zone (NMSZ). The objective of this continuing research is to use seismic-reflection methods to image shallow structure in an attempt to document the nature and timing of near-surface deformation. High-resolution seismic-reflection profiles have been collected across the Lake County Uplift, a topographic bulge (encompassing part of far western Kentucky) that is believed to be associated with contemporary seismicity in the central NMSZ.

Preliminary results indicate that shallow faults can be seen extending into Quaternary (possibly Holocene) sediments. Deformational styles include normal and reverse faults, a possible flower structure (near-surface expression of a strike-slip fault), and folding. Continuing research, supported in part by the U.S. Geological Survey, will attempt to determine the relationship between these shallow structural features and previously identified deeper deformation.

GRAVITY MAP OF KENTUCKY

James B. Harris

In 1978, the western sheet of the Bouguer gravity map of Kentucky was published by the Kentucky Geological Survey at a scale of 1:250,000. Because of difficulties in matching contours across map boundaries, the central and eastern sheets were never published. However, recent work has succeeded in joining the sheets together. The entire gravity map will be published at a scale of 1:500,000, and the 1:250,000-scale western sheet will be placed on open file.

Oil and Gas Data

OIL AND GAS MAPS OF KENTUCKY

David A. Williams, Brandon C. Nuttall, Joseph F. Meglen, Matthew Humphreys, X. Mara Chen, Anna E. Watson, and Kevin J. Wente

Most of the effort to update the Oil and Gas Map of Kentucky has been absorbed by the Atlas of Major Gas Plays of the Appalachian Basin project. A new 1:100,000-scale oil and gas map of the Pikeville Quadrangle was published in two sheets earlier in 1994. One map shows development and distribution of Devonian Ohio Shale wells of the Big Sandy Field. The other map shows development and distribution of pools exclusive of the Big Sandy Field. Work is underway to compile data for the Williamson sheet; publication is expected later in 1994. Other 1:100,000-scale maps will be published in the future. Sheets 1 and 2 of the 1:250,000-scale oil and gas map series in western Kentucky are currently being revised and will be completed as an updated overlay for the original printed maps in the future.

In addition to a series of published 1:100,000-scale maps, there are two target products for this project: a 1:500,000-scale oil and gas map of Kentucky to supplement the State geologic map, and an atlas of stratigraphic and spatial distribution of oil and gas production. Preliminary work with personnel from other KGS sections has laid the groundwork for an integrated GIS approach that will

utilize the digital base map version of the State geologic map.

RESERVOIR CLASSIFICATION OF TERTIARY OIL RECOVERY INFORMATION SYSTEM (TORIS) IN KENTUCKY

James A. Drahovzal, Brandon C. Nuttall, Matthew Humphreys, and Kevin J. Wente

The U.S. Department of Energy (DOE) developed the TORIS data base for the purpose of characterizing the Nation's oil resources with the intent to: (1) estimate potential domestic oil reserves, (2) project United States oil production potential, and (3) target research and development efforts for enhanced exploration, drilling, completion, and production technologies to exploit the existing domestic resource. For Kentucky, TORIS contains data for only five oil reservoirs, all located in western Kentucky.

Preliminary estimates of original oil in place have been compiled, and key fields have been identified that account for approximately 80 percent of the original oil in place in the eastern Kentucky portion of the Appalachian Basin. These fields represent oil production from 39 different stratigraphic intervals ranging from Pennsylvanian to Cambrian. Data are being compiled on these fields for inclusion in the TORIS data base. Data required by the project include field size in acres, number of producing wells, porosity, permeability, pay thickness, oil and water saturation, original oil in place, current production, and reserves. A literature search is being conducted to obtain published data. In the next year, the literature search will continue and geophysical log, core, and sample data will be inventoried and analyzed as needed to complete the required data sheets.

ATLAS OF MAJOR APPALACHIAN GAS PLAYS

James A. Drahovzal, Brandon C. Nuttall, Matthew Humphreys, X. Mara Chen, Anna E. Watson, Kevin J. Wente, and Theola L. Evans

This 3-year project was initiated October 1, 1991, with funding from the DOE Morgantown Energy Technology Center. Activities are coordinated with the Ohio, Pennsylvania, and West Virginia geological surveys through the Appalachian Oil and Natural Gas Research Consortium of West Virginia University. The project consists of six tasks: major play definition, data collection and compilation, atlas preparation, atlas review, atlas printing, and technology transfer.

Now in its third year, the project has completed four of the six proposed tasks. The two remaining tasks are atlas printing and technology transfer, and they will be completed by the end of 1994.

To date, production data from 16 companies have been collected for nearly 3,000 wells in eastern Kentucky. The data have been analyzed and incorporated into estimates of resources and reserves. Data sheets have been compiled for 475 reservoirs in 17 different gas plays. Stratigraphic information and completion data from over 16,000 wells have been studied and entered into a computer data base, which will be made available to the public, as part of the technology transfer phase. Basic reservoir parameters such as porosity, gas saturation, and pay thickness were obtained from the study of over 1,500 geophysical logs.

Kentucky plays studied include Play 14, the Middle Devonian to Lower Mississippian fractured shales; Play 21, the Lower Devonian–Upper Silurian unconformity ("Corniferous"); Play 23, the Upper Silurian Lockport–Big Six; Play 28, the Upper Ordovician "Trenton" Limestone; Play 30, the Middle Ordovician "St. Peter" Sandstone and Wells Creek Dolomite; and Play 32, potential plays of the Rome Trough and basal Cambrian. Additional regional plays that are important in Kentucky include Play 3, the Upper Mississippian Mauch Chunk sandstones ("Maxon"); Play 4, the Upper Mississippian Greenbriar–Newman Limestone ("Big Lime"); and Play 7, the Lower Mississippian Fort Payne Formation. In addition, a revised map for the top of the Precambrian basement was compiled for the atlas, a cross section was completed, and a new map showing tectonic features was developed. Technical presentations on these plays and the new basement structure map were made at the Twenty-Fifth Annual Appalachian Petroleum Geology Symposium, March 21–23, 1994, in Morgantown, West Virginia.

Drill Cuttings And Core Samples

COMPUTERIZATION OF CORE REPOSITORY DATA

Patrick J. Gooding

The primary goal of this project was to establish a computerized data base containing an index of all cores available for public use at the KGS Core Repository. Over 70,000 core boxes, representing about 700,000 feet of vertical drilling, were individually inspected, and an inventory list was compiled.

The catalog of cores available for public inspection at the Core Repository was completed during the year, and the manuscript is in review.

Water Resources

In order for Kentucky to maximize its economic potential, large quantities of usable water are necessary. Kentucky must plan for the wise use of its ground- and surface-water resources for the expansion of industry and urban areas, and to develop its mineral and agricultural resources.

Over the past 20 years not less than 10 Federal acts have been enacted to protect water. During this time, State regulatory agencies developed programs dealing with mining and mine reclamation, solid and liquid waste disposal, sewage disposal, water supply, oil and gas recovery, and agricultural practices. Over this past year, the State has concentrated on developing ground-water regulations to protect this vital resource. An understanding of the geology and hydrogeology of Kentucky is essential for development of these regulations and the optimum development, utilization, and management of the State's water resources. The Water Resources Section provides information to municipalities, industry, State and Federal agencies, and private citizens concerning the occurrence, movement, quantity, and quality of surface and ground water in the State.

Data necessary to maximize our water resources come not only from previously published studies, but new projects designed to meet the present and future demands of State and Federal programs and the needs of Kentucky's citizens. The Water Resources Section has directed much of its efforts over the past year to designing such projects and implementing them by drilling monitoring wells, sampling springs, and monitoring surface waters. In response to the 1990 Kentucky General Assembly's mandate that KGS establish a repository for all ground-water data collected by State agencies (KRS 151:035), and the appropriation of initial funds by the 1992 Legislature, KGS has developed the computer framework for the Repository and has begun acquiring data from other State agencies.

Urban and rural economic development is tied to the availability of water. The effect of land use on water quality and quantity is also an important factor in economic development because of regulatory policies. Therefore, basin-hydrogeology research is essential for future economic development in the Commonwealth. This type of research requires comprehensive data bases for both ground water and surface water. Data for surface water are collected in a cooperative program with the Kentucky Division of Water and the U.S. Geological Survey; data for ground water are collected from KGS research programs and from other state agencies, industry, and private citizens.

In order to achieve its mission during the past year, the Water Resources Section has conducted research in cooperation with the Kentucky Cabinet for Natural Resources and Environmental Protection; various groups within the University of Kentucky, including the College of Agriculture, Institute for Mining and Minerals Research, College of Engineering, and Department of Geological Sciences; and several Federal agencies, including the Soil Conservation Service and the U.S. Geological Survey.

For discussion purposes, Water Resources programs can be divided into four areas: Coal-Field Hydrology, Karst Hydrology, Water Quality, and Basin Hydrogeology. The following summaries describe the results of research projects conducted during the 1993–94 fiscal year.

Coal-Field Hydrology

STAR FIRE PROJECT: HYDROGEOLOGY OF A LARGE MINE-SPOIL AREA

David R. Wunsch, James S. Dinger, Daniel I. Carey, and C. Douglas R. Graham

The economy of Kentucky is highly dependent on the coal-mining industry, and especially so in eastern Kentucky. While coal production has experienced growth, mining-related jobs have declined 30 percent during the past decade because of more efficient mining methods and the advent of new technologies. Economic growth and diversity in the coal field are severely limited, in part by the steep topography and the lack of water resources. Cyprus Mountain Coals, a subsidiary of Cyprus Minerals, Inc., owns the 17,000 acres at the Star Fire surface mine, located in Knott, Perry, and Breathitt Counties. The company has an interest in the post-mine development of the property and is presently planning for alternative land uses after mining has been completed.

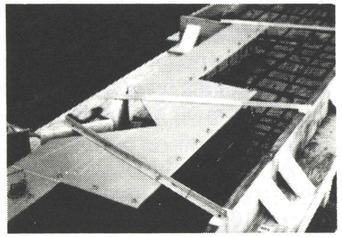
An estimated 10,000 acres of usable flat land will be created by the year 2010 at the Star Fire site through mountaintop-removal techniques, thus providing a site for new land uses and future eco-

nomic development. KGS has conducted an applied research program to determine the water resources at the site, which will be vital for the successful development of the site.

Surface-water flow has been measured using weirs and handheld flow meters. A V-notch weir equipped with digital data-recording capabilities was installed to monitor continuous surface-water outflow from the mine site, which will aid in determining the hydrologic budget. Data collected over 255 days showed an average discharge from the mine of 6.6 cubic feet per second, which is equivalent to about 4 million gallons per day. Eventually, the water budget for the reclaimed mine area, which includes the contributions derived from ground water from the spoil, will be estimated for the site.

Data interpreted from the 14 monitoring wells at the site indicate a zone of saturation at the base of the spoil that averages 21 feet in thickness and stores an estimated 1.4 billion gallons. Slug tests were performed in individual wells to determine the hydraulic characteristics of the saturated portion of the spoil. Hydraulic conductivity (K) values ranging from 2.0×10^{-5} to more than 9.0×10^{-4} centimeters per second were calculated for the spoil surrounding the wells.

Water-table elevation data from monitoring wells, springs, and ponds indicate that three saturated zones exist within the spoil: one in the interior section of the spoil, and two additional zones at lower elevations in the two adjoining hollow fills. Most likely these saturated zones are in hydrologic connection in the southeastern section of the spoil, but are separated because of the pre-mining topography in the northwestern section of the spoil.



A V-notch weir under construction. When in place in the stream, the weir will be upright.

Surface subsidence around the surface seals of the monitoring wells occurs throughout the spoil area. Some areas are subsiding at a maximum rate of 0.4 foot per year. Plans are presently underway to install a complicated array of subsidence monuments to accurately monitor vertical and horizontal movement related to spoil settlement.

Water samples are collected for chemical analysis on a semi-annual basis from the monitoring wells and major springs that crop out at the spoil's periphery. Wells located in the hollow-fill areas were found to be more responsive to precipitation and contain water that is less concentrated in dissolved constituents compared to wells located in the main spoil body. The analysis of water samples from all areas of the site reveals that the major dissolved constituents are calcium, magnesium, and sulfate.

Geochemical modeling revealed that the ground water in the interior of the spoil is near equilibrium or saturated with respect to gypsum, probably because of dilution. Plans for future water-quality monitoring include the installation of a continuous monitoring system at the mine outflow to determine seasonal variations.

The interpretation of hydrological, hydrogeological, and geochemical data has led to the construction of a conceptual model of ground-water flow at the site. Future plans call for verifying the model with mass-balance calculations of geochemical and hydrological data.

KGS produced a report on the quantitative issues for the creation of surface-water reservoirs on lands surrounding the reclaimed mine site. Site evaluations for reservoir locations, as well as estimates for size, volume, and the amount of time necessary to fill the basins, were calculated.

A manuscript titled "The Hydrogeology and Hydrogeochemistry of a Large Mine-Spoil Area: Star Fire Site, Eastern Kentucky" has been prepared and is expected to be published by KGS in 1994. Papers that described KGS research efforts at the site were presented at two international professional meetings covering water and mining-related issues.

GROUND-WATER GEOCHEMISTRY AND ITS RELATIONSHIP TO GROUND-WATER FLOW IN THE EASTERN KENTUCKY COAL FIELD

David R. Wunsch, James A. Kipp, Philip G. Conrad, Dwayne M. Keagy, Shelley A. Minns, and James S. Dinger

The Water Resources Section is conducting research to define natural background flow and chemical characteristics of ground water in the Eastern Kentucky Coal Field. Information concerning the background conditions of the hydrogeologic and geochemical regime in coal-mining areas is imperative for fair and effective implementation of Kentucky's ground-water protection regulations. Industries that operate in eastern Kentucky (coal mining, oil and gas, and landfills) are in need of this information for both permitting and compliance.

KGS ground-water studies conducted in eastern Kentucky suggest that distinct geochemical facies are related to specific zones of ground-water flow. Hydrogeochemical studies have been conducted at several representative sites in order to define the interaction between ground-water occurrence and natural water quality. The objectives of these studies are to (1) correlate the hydraulic characteristics of coal-bearing rocks with site geology, (2) characterize the occurrence, movement, and quality of ground water, (3) document the occurrence of trace elements and their relationship to specific ground-water types, and (4) gain a better understanding of the hydrogeologic characteristics of the area in order to initiate a meaningful ground-water monitoring scheme.

Data collection, which includes water-level measurements and the collection of water samples, has been continuing at a site approximately 1 mile south of the Star Fire Mine in Perry County. Data collected at this site will augment our knowledge of the geochemistry of ground water in eastern Kentucky and supplement data necessary for the creation of conceptual ground-water geochemical models for the Eastern Kentucky Coal Field. Additional data have been collected from a site in Leslie County, along with data collected with support from the Kentucky Division of Abandoned Mine Lands under a contractual agreement with KGS that was in effect from 1989 to 1992.

Constant-head pressure-injection tests were performed at several of the sites used for the collection of ground-water samples. These detailed tests document the importance of coal seams and shallow fractures to the movement of ground water in the region. These data are currently being summarized describing the hydraulic characteristics of Pennsylvanian rocks and providing insights into the complex movement and occurrence of ground water in eastern Kentucky.

Data and models generated from these ground-water studies will be valuable to regulatory agencies and the industries they regulate for permit requirements, and for definition and protection of aquifers, and will add to our knowledge of evolution of ground-water types in the Eastern Kentucky Coal Field.

HYDROLOGIC INVESTIGATIONS IN ROBINSON FOREST

David R. Wunsch and James S. Dinger

The University of Kentucky's Robinson Forest contains some of the largest undisturbed tracts of land in eastern Kentucky. This setting provides a unique opportunity to establish a monitoring network to determine background conditions for water-quality investigations as well as to collect valuable information regarding the interactions between recharge and discharge in forested basins in eastern Kentucky.

Ten monitoring wells were installed in two land parcels of the forest. Six of these wells were placed in the Laurel Fork tract, but a change in the mining plan by the contractor caused the destruction of these wells before many data were obtained. Four additional wells are located in the Clemmons Fork area of the main block of the forest property. Two of the Clemmons Fork wells have been placed near the forest boundary where active coal mining is occurring in order to monitor the changes, if any, in the hydrologic regime as mining progresses. Water-level data and water-quality samples were taken from the wells. Plans are under way to install digital data loggers to record water-level response to precipitation and the discharge of streams that drain the basins hosting the wells. These data will also be used to validate the interpretations and conceptual models derived from data collected at other sites.

In addition, water samples from seeps emanating from coal seams that crop out in the forest are being analyzed to determine their origin and mineralogical composition. Chemical precipitates associated with the seeps have been analyzed as well. Chemical data from water samples collected at the seeps will provide input for geochemical models that will aid in the determination of the origin and mineralogical makeup of the precipitates. This information will provide insight into the complexities of ground water and its relationship to secondary mineralization in the Eastern Kentucky Coal Field.

EFFECTS OF DEEP COAL MINES ON HYDROGEOLOGY

James A. Kipp, Shelley A. Minns, James S. Dinger, Daniel I. Carey, and Lyle V.A. Sendlein

Subsidence-related deformation and associated hydrologic changes are being evaluated at an active longwall coal mine in eastern Kentucky. The site selected for this investigation is on Edd Fork near Helton in Leslie County.

In longwall mining, a working face several hundred feet wide is advanced between parallel headings, producing a series of large, rectangular, mined-out panels. The face is temporarily supported during extraction of the coal by movable hydraulic jacks. As these supports advance with the face, the unsupported roof fractures into blocks that collapse into the mined-out area. The remaining overburden then subsides onto this rubble.

For this project, three cores were drilled (ridge-top, valley-side, and valley-bottom positions) to provide stratigraphic information for the study site. Pressure-injection

testing was also conducted in each core hole in 10-foot intervals using inflatable packers to isolate test sections. The resulting data provided documentation of the pre-mining hydraulic characteristics of the rocks over the area to be mined. Coaxial cables were later grouted into each core hole. These cables are being monitored using time domain reflectometry to evaluate rock deformation occurring in response to subsidence.

Information from the core holes was used to design 24 ground-water monitoring wells that were installed during the summer of 1992. Initial water-level data from these wells and the results of water-quality sampling indicate the presence of complex ground-water flow and hydrogeochemical systems that represent pre-mining conditions. A flume and rain gage measure the discharge of Edd Fork and collect precipitation data in the study basin so that changes in hydrology can be fully evaluated. Monuments for determining surface subsidence were also installed along the edge of the instrumented panel during the past year.

Data collected so far document some hydrologic changes and rock deformation in response to mining of the adjacent panel. Mining of the instrumented panel should be completed during summer 1994; monitoring will continue into the post-mining period. A final report is scheduled for completion by September 1995.

This study is a cooperative effort with the U.S. Office of Surface Mining, the Kentucky Department of Surface Mining Reclamation and Enforcement, the UK Department of Geological Sciences, the UK Institute for Mining and Minerals Research, and the coal industry. A project status report was submitted to the funding agencies in September 1993, and data from that document are available to the public as a KGS open-file report.

HIGH-VOLUME–HIGH-VALUE USAGE OF FLUE GAS DESULFURIZATION BYPRODUCTS IN UNDERGROUND MINES

Shelley A. Minns, Lyle V.A. Sendlein, and James S. Dinger

The objective of this new project is to determine the technical, environmental, and economic feasibility of placing flue gas desulfurization (FGD) byproducts into mine entries created by a highwall miner system. The highwall miner is a remotely operated, continuous mining system designed to recover coal up to 1,200 feet underground from horizontal entries along a highwall face. Solidified backfill derived from FGD material will be used as structural support for mined entries so that intervening pillars may be mined. Laboratory and field-scale demonstrations are planned to characterize the cementitious properties of FGD material, develop a remote delivery system for emplacement, and determine the leaching characteristics of the solidified material. Preliminary site investigations and environmental monitoring are the responsibility of the Kentucky Geological Survey and the Kentucky Water Resources Research Institute.

The study site is located in Greenup County, Kentucky, on property owned by Addington Resources, Inc. Mine-adit locations have been surveyed, and a plat of the site is completed. Three core holes were drilled near entryways to provide stratigraphic information. Pressure-injection tests were conducted in each hole on 5-foot intervals to document hydrologic properties of the strata. Drilling information was used to finalize a monitoring-well network to be installed during the summer of 1994. At least 1 year of baseline hydrologic data will be collected prior to backfilling.

This project is funded by the U.S. Department of Energy and Addington Resources, Inc., and managed by the UK Center for Applied Energy Research in cooperation with the Kentucky Geological Survey, Kentucky Water Resources Research Institute, UK Department of Civil Engineering, Kentucky Transportation Center, and UK Department of Mining Engineering.

Karst Hydrogeology

Karst areas of the State constitute one of the most important hydrogeologic provinces in Kentucky—over half of the Commonwealth is underlain by carbonate rocks with some karst development, and approximately 25 percent of the State has well-developed karst ground-water flow. Most karst areas are rural, and most residents there depend on wells for their individual water supplies; many community supplies in this region depend on large springs that are a result of karst hydrology. Karst conditions also exist under several metropolitan areas, including Louisville, Lexington, and Bowling Green. A thorough understanding of the hydrogeology of these regions is essential for protection of those water supplies because aquifers in karst terrain are easily contaminated by pollutants flowing into sinkholes and moving quickly through open conduits and discharging into streams and rivers. Such rapid movement also leads to flooding, which can cause considerable damage in urban areas.

During the past year published and new data have continued to be entered into the KGS Hydrologic Data Base (formerly known as the Kentucky Aquifer Research Data Base [KARD]). Such data include ground-water dye traces, potentiometric surface maps, water-quality data, cave maps, and water levels

in wells. The eventual products of this work will include ground-water basin maps, flow analyses, and water-quality maps. The ground-water basin maps are being compiled in cooperation with the Kentucky Division of Water, Ground-Water Branch.

Monitoring-equipment installation, data collection, and data analysis to study nonpoint-source pollution have continued from last year in several unique karstic settings. Field work is in coordination with the other nonpoint-source pollution studies being conducted in granular and bedrock aquifers, and is being conducted in cooperation with the University of Kentucky's College of Agriculture, Institute for Mining and Minerals Research, and Department of Geological Sciences, and the Kentucky Natural Resources and Environmental Protection Cabinet. Intensive field work has been conducted in Logan, Jessamine, Bourbon, and Woodford Counties.

IMPACT OF NONPOINT-SOURCE POLLUTION ON AQUIFERS AND SURFACE WATER IN LOGAN COUNTY, WESTERN PENNYROYAL PLAIN

James C. Currens, Joseph D. Cupp, and Lyle V.A. Sendlein

The Logan County project is well into its second year of federally funded activity. An open-file report of the first phase of the research has been drafted and is now being edited. A KGS report on the first 2 years of work is also being written. The goal of this project is to determine the loading, or mass flux, of pesticides, nitrate, and other pollutants discharging from the karst aquifer at Pleasant Grove Spring. Federal funding has been applied for and will be used to change a variety of agricultural practices in the basin; the expected improvement in water quality will be monitored. If improvement in the ground-water quality cannot be demonstrated on a basin-wide scale, in a real-world setting, then the effectiveness of the practices and the program's success in obtaining the producers' cooperation may need to be re-evaluated.

Mapping of the drainage basin by ground-water dye tracing is now essentially complete. A few optional dye traces remain to be conducted as opportunities present themselves, and several quantitative traces are also planned. In addition to defining the karst ground-water basin, the tracing work has revealed a trellis pattern to the underground drainage network, which will be defined in detail by the quantitative traces. This information is extremely valuable for interpreting the chemical data being gathered at Pleasant Grove Spring.

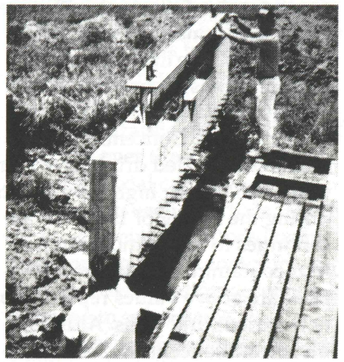
Water-level recorders were installed at four upstream sites last summer, and all monitoring sites are now instrumented. An inventory of domestic water wells was completed in the summer of 1993 and provided data for a potentiometric surface map and additional detail on the flow routes. Detailed maps of crop locations for 1990 and 1991 were completed in the fall of 1993, and the total acres for each crop are being computed.

From July 1, 1993, through April 20, 1994, seven comprehensive, 41 base-flow, 138 storm-event, and two rain-water samples were collected. Comprehensive samples were analyzed for general water-quality parameters and pesticide levels were determined by gas chromatograph. Base-flow and storm-event samples are analyzed primarily for pesticides by ELISA (enzyme-linked, immunosorbent assay, or immunoassay) and nitrate. In the Pleasant Grove Spring drainage basin, triazine herbicides (principally atrazine) are used extensively and are the pesticides most commonly found in the ground water. Other pesticides are found occasionally at low concentrations. The highest triazine concentrations occur a few weeks after application and peak during spring storms. Concentrations of triazines exceeded drinking-water standards during high-flow events during the spring of 1993. Nitrate continues to be the most ubiquitous contaminant, and concentrations are above values reported for non-agricultural areas. Although the nitrate concentrations are also below drinking-water limits, they do not seem to significantly decrease after the planting season. Sediment transported from fields is also a significant contributor to the contaminant load. Additional bacteriological studies are underway, and nitrogen isotope analysis to identify the source of the nitrate is planned. An open-file report is being prepared for release to the public.

IMPACT OF NONPOINT-SOURCE POLLUTION ON AQUIFERS AND SURFACE WATER, WOODFORD COUNTY, INNER BLUE GRASS

Dwayne M. Keagy, Alex W. Fogle, Angela M. Moore, Krista Gremos, and Lyle V.A. Sendlein

The Woodford County site is located at the University of Kentucky Woodford County Research Farm. Since the farm is owned by the University of Kentucky, farm practices can be controlled to facilitate research goals and at the same time help to develop effective agricultural practices. Initial reconnaissance suggests this site is unusual because two karst systems appear to exist on the farm. One system, perched on impermeable strata, creates springs on valley slopes above regional base level. The second is a deeper, more highly developed karst system with larger conduits, represented by fewer but higher capacity springs. A portion of the catchment area of these



Installing a V-notch weir.

springs is off the farm, as indicated by dye tracing and differences in water quality.

During the past year, dye tracing on the farm has continued. Three well nests containing thirteen monitoring wells and eight lysimeters have been installed to study ground water in corn-field, tobacco-field, and pasture settings. Intense monitoring for agricultural chemicals (pesticides and nutrients) and bacteria at springs, streams, and well nests took place throughout the fall and winter of 1993. Within the past year water level was measured at 390 monitoring wells, and 249 spring and stream-flow measurements were taken, as well as water-quality samples from 117 monitoring-wells, 92 lysimeters, 147 springs, and 101 streams. At this site it has been determined that the bedrock surface and confining strata act to locally impede the downward migration of contaminants to the level of the regional water table, although conduits within the rock mass act to concentrate and rapidly transport contaminants into and within the ground-water system. Detectable concentrations of pesticides were found in all springs near which they were applied. Triazines and metolachlor were the most commonly detected herbicides. In general, the highest herbicide concentrations were found in the shallowest monitoring points at the corn-field well nest. Nitrate was the most frequently detected agricultural chemical in ground water throughout the study area. Nitrate concentrations exceeded standard drinking water limits in 12.5 percent of the samples collected. At well nests, nitrate concentrations were found to decrease within the bedrock. Often some of the highest nitrate concentrations were detected at the soil–bedrock interface. Occurrence of nitrate in ground-water systems is dependent upon numerous factors.

In the spring of 1994, sampling procedures were modified in order to facilitate a better understanding of the occurrence of nitrate and the effect new crop patterns will have on the ground-water system. Bacterial counts in springs and streams were found at times to exceed drinking-water standards. The predominant source of bacterial contamination of waters at the farm was determined to be animal waste.

A KGS open-file report has been released that discusses interim finding of this continuing study.

IMPACT OF NONPOINT-SOURCE POLLUTION ON AQUIFERS AND SURFACE WATER IN BOURBON COUNTY, OUTER BLUE GRASS

Dwayne M. Keagy, Steven K. Hampson, and Lyle V.A. Sendlein

The Bourbon County study was initiated to investigate the relationship between the application of agricultural chemicals and ground-water quality. Of special interest to this study was the occurrence of ground water at the soil–bedrock interface and in the epikarstic zone in both fracture and inter-fracture zones. Two sites were chosen: one, a cattle pasture, and the other, a corn field.

Ground-water dye tracing at both sites answered a number of questions. In 1992 and 1993, ground-water was monitored for pesticides, nutrients, and cations and anions at both sites, using springs and nests of shallow monitoring wells and soil suction lysimeters. The stratigraphically highest occurrence of ground water was found to be in the epikarstic zone in the highly weathered bedrock beneath fracture traces. Interfracture-zone ground water moves across the bedrock surface and through the shallow epikarstic zone to fracture zones, where it is captured by conduits and discharged at springs.

Nitrogen fertilizer and triazine and metolachlor herbicides were applied at the corn site. No pesticides or nutrients were applied at the pasture site. Herbicides were only detected near where they were applied. Triazine concentrations exceeded standard drinking water limits in only 5 percent of the samples collected. Triazine concentrations in ground water were found to peak immediately after application and then fall to near or below detection within 1 month. Nitrate was the most frequently detected agricultural chemical in ground water throughout the study area. Nitrate concentrations exceeding standard drinking-water limits occurred in only 6 percent of the samples collected. All samples exceeding drinking-water limits were collected from the corn site. The highest nitrate concentrations were seen during the winter months. At the corn site nitrate concentrations decreased with depth in interfracture zones, while no significant change in concentration with depth was found in fracture zones.

A KGS open-file report describing the preliminary results of this study has been released, and a Master's thesis has been written

concerning the detailed findings of this research.

FLOODING OF THE SINKING CREEK KARST AREA IN JESSAMINE AND WOODFORD COUNTIES, KENTUCKY

James C. Currens and C. Douglas R. Graham

A report on the flooding of Sinking Creek Karst Valley in the Garretts Spring drainage basin, Jessamine and Woodford Counties, was printed this year and is now available for purchase (Series 11, Report of Investigations 7). The report explains the hydrology of the cave conduits carrying water from Sinking Creek to Garretts Spring and the conditions leading to flooding in Sinking Creek Karst Valley. Results from a computer model predict flood response of the area under varying land-use and precipitation conditions. Relative merits of several possible solutions to flooding are discussed.

KGS has discontinued field activity in this study area, and all permanently installed equipment is now being operated by the University of Kentucky College of Agriculture.

Water Quality

All of the projects described above involve the characterization of ground-water flow and quality in different types of hydrogeologic terrains. The Water Resources Section is also investigating water-quality issues associated with nonpoint-source pollution, riparian vegetation, surface-water runoff, and potential deep aquifers in the Blue Grass Region of Kentucky.

Section 319 of the 1987 Federal Clean Water Act regulates a large variety of pollutants that enter waters from sources that cannot be pinpointed. This type of pollution is called nonpoint-source (NPS) pollution and includes contaminants from sources such as agriculture, construction, forestry, mining, septic-tank wastes, and urban storm runoff. In response to the Federally mandated program to measure and mitigate the effects of NPS pollution, the Kentucky Division of Water has developed a program, and the Kentucky Legislature has provided funds to the University of Kentucky College of Agriculture, to investigate the effects of agricultural practices on ground water in Kentucky. The Kentucky Geological Survey is participating in both of these programs by conducting hydrogeologic investigations.

Modern agricultural practices rely on the use of pesticides, herbicides, and insecticides to increase crop yields. In addition, agricultural construction such as feed lots and waste lagoons concentrate animal wastes, leading to potential contamination of aquifers. In many instances these aquifers are potable water for the region and serve as sources for irrigation and livestock watering. At present, KGS is investigating 10 sites in coordination with the University of Kentucky's College of Agriculture, Department of Geological Sciences, and Institute for Mining and Minerals Research, and the Kentucky Natural Resources and Environmental Protection Cabinet. Major emphasis this past year has been placed on sites in Logan, Jessamine, Woodford, and Bourbon Counties (*see* Karst Hydrogeology *above*), and Daviess, Hopkins, and Hickman Counties (*see below*). These sites represent diverse hydrogeologic settings in which the movement and fate of agricultural chemicals may vary greatly. In addition, Survey staff members serve as technical representatives to the Ground-Water Education and Rural Water Testing Program, which is co-sponsored by the UK College of Agriculture, Kentucky Divisions of Water and Conservation, and Kentucky Farm Bureau Federation, Inc.

The Ground-Water Education and Testing Program was conducted from 1989 to 1992; 4,862 wells in 108 of Kentucky's 120 counties were tested. Samples were tested for ammonia, nitrite-nitrogen, nitrate-nitrogen, chloride, sulfate, conductivity (dissolved solids), alachlor (Lasso®), and triazine (atrazine). A summary of the data was published in KGS Information Circular 44, "Quality of Private Ground-Water Supplies in Kentucky." It is anticipated that another round of sampling will occur in 1994–95, although the scope of this testing has not been decided.

IMPACT OF NONPOINT-SOURCE POLLUTION ON AQUIFERS AND SURFACE WATER IN HICKMAN COUNTY, JACKSON PURCHASE REGION

Philip G. Conrad, Lyle V.A. Sendlein, and Carl Petersen

Ground-water quality is being studied in a 2.5-mile-long drainage basin in Hickman County. This site was chosen because of its extensive cultivation with row crops and the use of fertilizers and pesticides, its geology (loess, continental deposits, and semi-consolidated sandstone), which is representative of most of the Jackson Purchase Region, and the use of ground-water supplies by residents.

Samples from domestic wells continue to be analyzed monthly for nitrate, common pesticides, total organic carbon, and ammonia-nitrogen. Water levels in the wells are measured monthly. Seventeen monitoring wells have been installed to collect water samples and measure water levels in both perched ground water and the Eocene aquifer. Monitoring wells range from 5 to 119 feet in depth, and are sampled more frequently in the spring after application of

pesticides and nitrogen fertilizers. Pressure transducers have been installed in six wells to record fluctuations in water level of the perched and regional ground-water systems. These water-level data will be used in conjunction with water-quality data to model ground-water flow in this setting.

Triazine pesticide detections were all below the MCL (maximum contaminant level set by the U.S. EPA) for atrazine herbicide during 3 years of sampling the aquifer for the basin. Nitrate-nitrogen concentrations regularly measure over the MCL in some of the private wells tested, and this is a focus of current research at the site.

IMPACT OF NONPOINT-SOURCE POLLUTION ON AQUIFERS AND SURFACE WATER IN HOPKINS COUNTY, WESTERN KENTUCKY COAL FIELD

Philip G. Conrad, Jeffery D. Snell, and Lyle V.A. Sendlein

Ground-water quality is being studied at a tilled farm field in Hopkins County that has been planted in corn for most of the last 40 years. This farm represents outlying areas of the Western Kentucky Coal Field, with a fluctuating water table, whereas the Daviess County site (*see below*) represents lowland farms in the northern and central parts of the coal field with a steadily high water table. The geology at the Hopkins County site is generally lacustrine deposits of silt and clayey silt above sandstone, shale, and coal bedrock at a depth of 26 feet. Tile drains discharge into a local creek whose bottom is 10 feet lower than the farmed land. Nine monitoring-well screens range in depth from 5 to 28 feet. Samples were collected most frequently after application of pesticides and nitrogen fertilizers, and were analyzed for these constituents.

Nitrate-nitrogen concentrations were above the MCL in the shallowest ground water, but ground water from bedrock was consistently far below the MCL. Atrazine and simazine herbicides were rarely detected below 8 feet in depth, and then only at trace concentrations. Concentrations in ground water above 8 feet in depth were lower in 1993 than in 1992 because of dryer conditions in the weeks during and after herbicide application. Dry conditions led to greater degradation of the herbicides before there was much recharge of ground water from rainfall. Sampling may continue at the site if land-use practices change from those used in 1992 and 1993.

IMPACT OF NONPOINT-SOURCE POLLUTION ON AQUIFERS AND SURFACE WATER IN DAVIESS COUNTY, WESTERN KENTUCKY COAL FIELD

Philip G. Conrad, Jeffery D. Snell, and Lyle V.A. Sendlein

Ground-water quality is being studied at a farm field and a nearby wooded lot in Daviess County. This is one of two farm sites currently being studied in the Western Kentucky Coal Field (*see above*). The geology of the farm and wooded sites consist of lacustrine deposits of silty clay and clay above a shale, sandstone, and coal bedrock that lies 23 to 40 feet below the flat ground surface. Old tree roots left over from when the crop field was wooded affect ground-water flow in the upper 10 to 14 feet of sediments at the site. The farm is tile drained, and the closest drainage ditches are about 6 feet deep. The farm field and wooded lot occasionally flood during wet years. Nine monitoring wells in the farm field range from 2 to 70 feet in depth, and one lysimeter is installed at a depth of 5 feet. Eight monitoring points in the woods are installed to similar depths for comparison with results from wells at the farm field. Samples were collected most frequently after application of pesticides and nitrogen fertilizers, and were analyzed for these constituents. Sampling in the woods was halted after July 1992 when water-quality patterns became evident. Samples are analyzed for nutrients, pesticides, and common ions found in ground water. Nitrate-nitrogen concentrations remained below 1.5 mg/L in ground water at the crop and woods sites because of efficient denitrification. Metolachlor and 2,4-D herbicides applied at the site in 1992 moved downward through upper sediments most readily via root macropores, but vertical movement of the herbicides was greatly diminished below the deep root zone.

Sampling of the crop wells may continue if land-use practices change significantly from those used in 1992 and 1993.

EFFECTS OF RIPARIAN VEGETATION ON WATER QUALITY: MODELING AND EXPERIMENTAL STUDIES

Alex W. Fogle and Daniel I. Carey

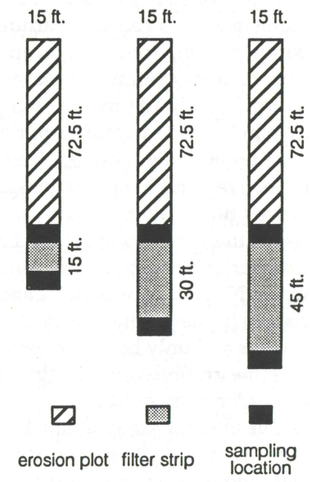
Because of the diffuse nature of nonpoint-source pollution, conventional techniques used to measure point-source pollution are inappropriate. Through physical reasoning and analysis of limited data, several researchers have concluded that the best way to control nonpoint-source pollution is better land management and the use of best management practices (BMP's), which control pollution at its source. A goal of BMP utilization is to diminish the environmental impact of land-use activities while maintaining the productivity and use of the land. One BMP recommended by the U.S. Soil Conservation Service to control nonpoint-source pollution is the use of a riparian zone, which is a zone of

planted or indigenous vegetation on the bank of a natural water course. A common type of riparian zone is a grass filter strip (GFS).

The objectives of this project are to (1) characterize the movement of sediment and dissolved solids through naturally occurring GFS's, accounting for natural variation in microtopography and channelized flow, (2) characterize the movement of dissolved solids into the vadose zone of VFS's in karst regions, and (3) develop predictive models to evaluate the impact of GFS's on water quality.

Six test filter strips located on UK's Spindletop Farm in Fayette County were selected for study in 1990. These filter strips were located immediately downslope of erosion plots established in 1989. The erosion plots were identical in size and consisted of three conventional tillage plots and three no-tillage plots. The filter strips ranged in length from 15 to 45 feet, with each length of strip duplicated below a conventional and no-tillage plot. Each filter strip's microtopography was determined over a 6 inch by 1 foot grid.

Twelve test runs were conducted on the six plots in 1991.



Schematic diagram of the erosion plot and filter-strip arrangement.

Each test was designed to simulate natural rainfall occurring on a field subjected to common agricultural practices. Simulated rainfall was applied at a rate of 2.5 inches per hour for a long enough period to produce 2 hours of runoff from the erosion plots to the grass filters.

Runoff onto and from the GFS's was sampled approximately every 5 minutes. These samples were analyzed to determine runoff rate, sediment concentration, sediment particle-size distribution, and concentrations of atrazine, ammonium nitrogen, nitrate nitrogen, and phosphorus. Inflow and outflow hydrographs and sediment graphs were also developed.

All filter strips trapped more than 90 percent of the sediment introduced to the filters, regardless of filter length and tillage practice. The filters also trapped more than 90 percent of atrazine and nitrogen introduced from the erosion plots. Phosphorus trapping efficiency exceeded 85 percent for all filters. The best control was obtained with 30-foot filter strips below no-tillage plots. It was expected that the 45-foot strips would perform better than the 30- and 15-foot strips, but extreme channelization on the 45-foot strips considerably reduced the area subjected to runoff.

A model of filter-strip channelization, sediment transport, and trapping has been developed. The model performs very well in predicting the trapping efficiencies of the six test filter strips.

Project data and information have been published in a KGS publication, "Impact of Riparian Grass Filter Strips on Surface-Water Quality" (Series 11, Information Circular 46), and in other scientific publications ("A Low Head Loss Sampling Device for Monitoring Inflow to Natural Vegetated Filter Strips," "Water Quality Impacts of Natural Riparian Grasses: Part I. Empirical Studies," "Water Quality Impacts of Natural Riparian Grasses: Part II. Modeling Effects of Channelization on Sediment Trapping"). This project was conducted in cooperation with the departments of Agricultural Engineering and Agronomy at the University of Kentucky.

DETERMINISTIC MODEL OF CHANNEL HEADWALL EROSION: INITIATION AND PROPAGATION

Alex W. Fogle

Upland erosion from rill and inter-rill areas has been the subject of intensive investigations in the past. To date, however, no complete channel erosion models have been developed for small upland streams. The emphasis in this project was on modeling the initiation and propagation of headcut erosion on small upland streams with intermittent or small base flows.

Models were developed or gleaned from the literature that predict channel erosion resulting from shear in gradually varied flow, shearing forces resulting from submerged and partially submerged jets, and shearing forces resulting from free jets impinging upon a plunge pool. These models were linked with a runoff routing algorithm and a pseudo–three-dimensional channel-geometry model to develop the CHANNEL model. CHANNEL predicts general channel erosion resulting from time-varying flow, as well as the development and propagation of channel headwalls.

Development of all algorithms of the CHANNEL model was completed. CHANNEL has been alpha-level tested to some degree, but model testing was halted because of lack of funding. The free-jet profile and overfall shear stress distribution components of the model were tested using data collected both here at the University of Kentucky and at the U.S. Department of Agriculture Plant Science and Water Conservation Lab-

oratory in Stillwater, Oklahoma. These components appeared to perform well in comparison with the data.

The CHANNEL model makes predictions of changing channel geometry due to erosion and deposition. It also predicts streamflow sediment load with space and time. The model works reasonably well in scenarios where the headwall is formed and begins to propagate upstream. The model has numerical difficulties in cases where the scour hole is in transition from a submerged jet to a free jet. These difficulties were not resolved before funding ended.

A paper detailing the free-jet profile and overfall shear stress distribution components of the CHANNEL model, "Modeling Free Jet Trajectory at an Overfall and Resulting Shear Stress Distribution in a Plunge Pool," has been published, as well as the final project report, "CHANNEL, a Model of Channel Erosion by Shear, Scour, and Channel Headwall Propagation: Part I. Model Development."

The project was conducted cooperatively with the University of Kentucky Department of Agricultural Engineering and was funded by the U.S. Army Research Office.

PRODUCTION OF FRESH WATER FROM THE KNOX GROUP IN CENTRAL KENTUCKY

James A. Kipp

A few deep wells (800 to 1,000 feet deep) produce fresh water in central Kentucky. These wells are completed in the top of the Cambrian–Ordovician Knox Group. The primary objectives of this investigation are to (1) identify areas where the Knox has been demonstrated to contain potable water, (2) review available information on hydraulic characteristics so that the quantity of water potentially available from Knox wells can be estimated, and (3) evaluate water movement in the Knox, including the identification of possible recharge and discharge areas and the direction and potential rate of water movement.

The Kentucky Geological Survey, because of the great expense of drilling wells to the Knox, has relied upon well drillers and their customers to identify new Knox water-supply wells for testing and water-quality sampling. Since 1985, data for new Knox wells have also become available as a result of the Certified Water Well Drillers Program administered by the Kentucky Division of Water. The distribution and quality of the information is still quite limited, but interest in the Knox aquifer remains because short-term variations in quantity and quality are less likely in this deep formation than in the near-surface karst aquifer that is more commonly used for rural domestic water supplies in central Kentucky.

A summary of the currently available information is being developed into a KGS report titled "The Knox Aquifer in Central Kentucky." The draft of this manuscript has been completed, and it is currently in revision following technical peer review.

EFFECT OF COAL ASH DISPOSAL ON THE HYDROLOGIC ENVIRONMENT

Shelley A. Minns, Lyle V.A. Sendlein, James S. Dinger, and James C. Currens

For the past 4 years the UK Institute for Mining and Minerals Research, the Kentucky Water Resources Research Institute, the UK Department of Geological Sciences, and the Kentucky Geological Survey have been conducting research on the effects of coal-ash disposal in three different hydrologic environments. The environments are a karst system, a river alluvium setting, and an ash fill in a bedrock valley. All disposal sites are operated by the East Kentucky Power Cooperative. The karst system is situated next to Lake Cumberland on the Ste. Genevieve and St. Louis Limestones and the Salem and Warsaw Formations, all of Mississippian age. The sites have both an active ash lagoon, where an ash-water slurry is used to transport and dispose of ash, and a closed-out lagoon, where no water was ponded nor ash delivered since 1978. Three monitoring wells were drilled in the ash at the closed-out lagoon to monitor water quality. Mean concentrations of lithium and manganese for these wells are at least one order of magnitude greater than baseline ground-water concentrations. Arsenic exceeded the drinking-water MCL in one well. Springs downgradient from the closed-out lagoon meet established MCL's and SMCL's (Secondary Maximum Contaminant Level) and are similar in water quality to baseline springs. Water in the active ash pond is similar in major-ion composition to that in Lake Cumberland. Ash-pond water exceeds the drinking water SMCL for manganese and contains barium, boron, copper, iron, lithium, and silicon, in concentrations that are approximately 10 times greater than in Lake Cumberland. Springs discharging downgradient from the active pond have a water-quality type that is intermediate between the surface water from Lake Cumberland and baseline ground water. No MCL's or SMCL's are exceeded in these downgradient springs and only boron exceeds baseline ground-water quality by one order of magnitude.

The alluvial site is situated next to the Kentucky River. Twenty-eight monitoring wells were drilled to different depths ranging from 10 to 65 feet in the alluvium and used to characterize the flow system and the ground-water quality. The ground-water system has the potential to receive recharge from surrounding bedrock, an active ash-pond slurry system, rainfall through dry landfilled ash, and from the Kentucky River during flooding. These sources produce three different ground-water zones, which are characterized as follows. The deep zone (near bedrock) has a low Eh (greater than –80) and high concentrations of iron and ammonia nitrogen. Concentrations fall below detection limits for sulfate and trace metals. The intermediate zone is recharged by the ash pond and has relatively higher Eh (greater than 100), lower concentrations of iron and ammonia nitrogen, median sulfate concentrations (114 mg/L), and arsenic concentrations below detection limits. The shallow ground-water zone is recharged through the dry landfilled ash and has higher concentrations of nearly all cations and anions, including sulfate (less than 800 mg/L) and arsenic (0.9 mg/L), and low Eh (less than –100).

A Master's thesis and a doctoral dissertation, both under the direction of Lyle Sendlein of the UK Department of Geological Sciences, were completed in conjunction with this project. A KGS publication summarizing the geochemistry of the site is being reviewed.

The bedrock valley fill site is located in northern Kentucky. The bedrock is composed of the Kope, Fairview, and Grant Lake Formations, all of which have relatively low hydraulic conductivity except in the upper few tens of feet where fracturing caused by natural rock weathering has occurred prior to ash being placed in the landfill. The ash and scrubber sludge are deposited in a dry state, but the lower portion of the ash fill is saturated, as indicated by a series of monitoring wells installed to different depths in the landfill and underlying bedrock. It appears that placing the 75-foot-thick landfill into the valley has allowed the water table from the near-surface fracture system to rise into the ash. Ground-water quality from the ash is a calcium sulfate facies, and although antimony and arsenic MCL's are exceeded on occasion in wells monitoring the ash fill, no MCL's are exceeded in the bedrock wells. A Master's thesis on this phase of the project was also completed under the direction of Lyle Sendlein.

Basin Hydrogeology

GROUND WATER IN THE KENTUCKY RIVER BASIN

Daniel I. Carey, James C. Currens, James S. Dinger, James A. Kipp, David R. Wunsch, and Philip G. Conrad

Members of the Water Resources Section at the Kentucky Geological Survey have completed a number of studies on ground water in the Kentucky River Basin within recent years. These studies have covered such diverse topics as the effects of oil production on water quality, the occurrence of high barium concentrations in ground water of eastern Kentucky, ground-water geochemistry in eastern Kentucky, a reconnaissance of ground-water resources, production of fresh water from the Knox Group, and the quality of domestic well water.

A summary of KGS research, and data from local, State, and Federal sources, is being developed into a KGS report, "Ground Water in the Kentucky River Basin." The report will provide a comprehensive look at what we know about ground water in the basin. It will provide up-to-date information on ground-water usage and the potential for developing additional ground-water supplies. The report will also provide an overview of ground-water quality, including an examination of human activities that may threaten ground-water resources, and a discussion of contaminants that occur naturally in the basin.

The report is non-technical, but will contain an extensive bibliography of ground-water literature and references for technical readers. A draft report is currently in preparation.

WATER RESOURCES PLANNING AND MANAGEMENT IN THE KENTUCKY RIVER BASIN

Daniel I. Carey

Broad-based support for water-resources planning requires the dissemination of information on issues, alternatives, and the consequences of policy decisions. In general, this information must be gathered from a variety of sources and summarized in a manner that clearly displays the information. As part of its research activities, the Kentucky Geological Survey has begun assembling a spatial data base for water resources planning and management.

Spatial data on soils, ground water, water quality, demographics, oil and gas activities, topography, and political subdivisions were entered into the ARC/INFO geographic information system at KGS. These data and the GIS were used in water, coal, and petroleum resource studies. The development of the spatial data base using data from existing sources will continue.

HYDROLOGY OF MINED WATERSHEDS

Daniel I. Carey

Surface-water monitoring stations have been installed in four watersheds in different areas of eastern Kentucky in order to study basin hydrogeology.

The station on Edd Fork in Leslie County, a watershed of less than

200 acres, provides data for hydrogeologic studies of the impact of underground mining on water supplies.

The station on Long Fork in Knott County provides data to evaluate water resources and post-mining development in the area.

Two monitoring stations have been installed on adjacent small watersheds in the University of Kentucky's Robinson Forest. These stations will collect flow and water-quality data that will be used to evaluate the impact of mining on surface and ground water in the area.

Participants in the Water Resources Section Field Workshop at Laurel River Dam Spillway, London, Kentucky, examine the bedding features.

COMPUTER AND LABORATORY SERVICES

The Computer and Laboratory Services Section operates state-of-the-art laboratory equipment and acquires or develops computer software and hardware. These tools enable researchers to analyze geologic and hydrogeologic data and collect, store, and manipulate data for reports, maps, charts, and other products for use by industry, government, and the private sector.

Computer Services

A building-wide computer network allows KGS to interconnect various mini-, desktop, and personal computers. This versatility allows many types of operating systems to exchange information. The network in the building has also been bridged to the University of Kentucky Network (UKnet), which, in turn, is linked to most of the national networks.

KGS's four-node Local Area VAXcluster (LAVc), which is an operating environment specific to Digital Equipment Corporation's (DEC) VAX and ALPHA series of computers, consists of an ALPHA 2100 Server, ALPHA 3000 model 600, VAX 8550, VAXstation 4000 model 60, and a VAXstation 4000vlc. In addition, various MS-DOS–based personal computers perform functions such as Computer Aided Design (CAD), presentation graphics, scanning, and other extraordinary tasks that cannot be accomplished on other computers. Peripheral equipment includes large-format plotters and digitizers, high- and medium-speed printers, and long-document scanners. Software includes database and report-writing facilities (DEC Rdb, VAX DATATRIEVE, and SMARTSTAR), wordprocessing and desktop publishing (MASS-11 and INTERLEAF Desktop Publishing System), geologic modelling (MINEX and SURFACE III), computer-aided drafting and presentation graphics (AutoCAD, FreeLance Plus, Harvard Graphics, Corel Draw), and Geographic Information Systems (GIS), which include ARC/Info running on a Digital ALPHA workstation and GRASS, which operates on a SUN Sparc10.

Personal Computer Local Area Network

In 1992, the KGS decided to fully integrate its growing number of personal computers (PC's) into the Local Area Network (LAN). DEC's PathWorks LAN is being used because it utilizes Digital's OpenVMS server, where our large geologic and hydrogeologic data bases are stored; PathWorks also has the advantage of operating across several server and desktop client operating systems (i.e., DEC VMS and ULTRIX, SUN UNIX, PC DOS, UNIX, OS/2, and MACINTOSH OS).

Overall, the LAN has been a very successful tool for KGS researchers. Many users are discovering different methods for analyzing data and preparing reports and presentations. With the integration of the KGS data base, KGS personnel are able to provide a higher level of services to the public by using relatively easy-to-use PC software.

In order to meet the growing needs of the PC LAN, KGS has upgraded its VAX 8550 to a Digital ALPHA 2100 server. This machine is designed for an LAN environment rather than an interactive character-cell terminal, which characterized the old technology. Also, because of the growing amount of data collected by researchers, KGS expanded its disk storage capacity to over 20 gigabytes.

In addition to the hardware upgrade, KGS plans to hire a new staff person to administer the LAN and help users with the many different applications available to them on the network. This person will also aid in the coordination, collection, transfer, and dissemination of data from various network resources (such as the INTERNET "Superhighway") that are needed by KGS personnel for their public service and research responsibilities.

Enhancements to the Public Domain Geologic/Hydrologic Data Base

Since 1983 the Kentucky Geological Survey has been developing and maintaining a collection of computerized geologic and hydrologic data pertaining to the Commonwealth of Kentucky. They make up the most detailed and comprehensive collection of petroleum, coal, water, and limestone data on Kentucky available to researchers and the general public.

Currently, KGS is using relational-data-base and query-by-forms technology to provide access to these extensive computerized geologic/hydrologic data sets. This state-of-the-art data storage and retrieval system efficiently manages, retrieves, and manipulates the ever-expanding and diverse public-domain data sets.

Recently installed software enhancements have increased data-base functionality in a number of ways. It is now possible to store scanned images, photographs, or video recordings in the data base. When fully implemented, this will allow users to do such things as:

- Examine computerized core descriptions while viewing photographs of the core
- Review information about an oil well while viewing the scanned images of electric logs of the well.

An additional advantage of this upgrade is that it will allow staff using PC's running Microsoft Windows 3.1 applications access to data from the relational data base. Windows applications such as Excel, Word for Windows, Quattro Pro, Lotus 123 for Windows, and Microsoft Access (1.1 or higher) can now easily download and use information from the KGS data base.

During the next fiscal year additional data sets will be added to the data base and existing data sets will be enhanced and updated. This new information is a result of KGS research projects and data solicited from private industry and government agencies. Ultimately hardware and software will be developed to provide direct public access to the data base. This will be accomplished in two ways: through public-access data stations in the Geologic Data Center at KGS and remotely through modems. To provide users with an intuitive interface to the data base, a query-by-form user interface will be perfected. It will allow users to move through the various data base components by selecting options from a series of menus. Data searches can be made by typing search parameters directly onto a form and striking a single data retrieve key. Hard-copy reports and ASCII files can be generated easily by selecting the appropriate records and striking a single defined key. This easy-to-master user interface will allow people with little or no computer expertise to access and manipulate large, complex data sets without having to know programming languages, syntax, or formatting codes.

Laboratory Services

The KGS laboratory facilities analyze the chemical and physical characteristics of water, rock, coal, oil and gas, and other natural resources. The laboratories make use of state-of-the-art automated equipment to provide researchers with the necessary data to complete their geologic and hydrogeologic reports. KGS will be replacing its current, in-house-developed Laboratory Information System (LIMS) with a LIMS based on PC-LAN in order to meet the information-processing requirements of the laboratory such as sample login, data storage, quality assurance, auditing, and reporting of results.

The laboratory facilities at KGS include the following analytical equipment/capabilities:

(a) for metals:
- Inductively Coupled Argon Plasma (ICAP)
- Flame Atomic Absorption (FAA) and Graphite Furnace Atomic Absorption (GFAA)
- X-Ray Florescence Spectrometry (XRF)

(b) for organics and pesticides:
- Gas chromatographs with Mass Selective, Flame Ionization, Electron Capture, Photoionization, Electrolytic conductivity, and Nitrogen-Phosphorus detectors
- Immunoassay for pesticides
- Total Organic Carbon

(c) for mineralogy:
- X-Ray Diffraction Spectrometry (XRD)

(d) for coal quality:
- Proximate Analysis (Leco MAC 400 Determinator)
- Ultimate Analysis (Leco CHN 600)
- Total Sulfur (Leco SC-444)
- Calorimeter (Leco AC 300)
- Ash Fusibility (Leco AF 600)

The Fuels Division of the Laboratory Services Section analyzed over 500 coal and mineral samples for coal quality and mineralogy. The laboratory participates in two round-robin testing programs for coal samples: the Interlab Network, operated by Standard Laboratories, Inc., and Service Program for the Evaluation of Codes and Standards, operated by CANMET.

During the year over 1,450 water samples were received in the Water Division for the analysis of metals, organic pesticides, and other water-quality parameters such as acidity, hardness, inorganic anions, and dissolved and suspended solids (a 20 percent increase over the 1992–93 fiscal year). The Water Laboratory also participates in both the USGS Standard Reference Sample Program and the EPA Water Supply Laboratory Performance monitoring programs.

PUBLICATIONS

One of the major functions of the Kentucky Geological Survey is making the results of research projects and field investigations readily available to the public. Publication of this information serves to disseminate geologic data generated by Survey staff, members of cooperating agencies, and other earth scientists doing research pertaining to Kentucky's geology and mineral resources. The Survey also publishes the proceedings of technical sessions and symposia, and guidebooks for geologic field conferences.

Publications of the Kentucky Geological Survey are made available to the public at a nominal cost and receive widespread distribution. Maps and reports are available for purchase from the Publication Sales Office, which is located in the Mining and Mineral Resources Building at the corner of Rose Street and Clifton Avenue on the University of Kentucky campus.

In addition to published reports, KGS also maintains an extensive collection of open-file reports, maps, manuscripts, theses, and other material, including coal-thickness data, logs of core holes, sample descriptions, seismic network data, and gravity base station networks. Copies of most U.S. Geological Survey open-file reports dealing with Kentucky geology are also maintained. Some of the material will eventually be published, but has been placed on open file in order to make the data available for public use prior to publication. Open-file reports are available for inspection at Survey offices in the Mining and Mineral Resources Building on the University of Kentucky campus during regular office hours. Copies of materials that can be reproduced are available for purchase.

Computer-plotted overlay maps showing the locations of oil and gas wells are available by 7.5-minute quadrangle. These maps are plotted on semitransparent material so that they may be used in conjunction with topographic or geologic maps available at the same scale. Locations are shown for all wells in the Survey's computer data base at the time the overlay map is plotted. Computer-generated well lists are available to accompany the maps.

The following publications were issued by the Kentucky Geological Survey during the 1993–94 fiscal year.

Bulletins

B 4. *Gas Exploration in the Devonian Shales of Kentucky*, by Terence Hamilton-Smith, 31 p.

Devonian shales, known variously as Ohio, Chattanooga, and New Albany Shales, constitute an important economic resource in Kentucky. Bulletin 4 summarizes information about depositional environment, organic content, hydrocarbon generation and migration, reservoir characterization, shale-gas resources, and future exploration potential. Geochemical evidence indicates that Devonian shales have acted as source rocks for much

Customers browse in the Publication Sales Department.

of the oil in both the Illinois and Appalachian Basins, as well as natural-gas accumulations such as the giant Big Sandy Field in eastern Kentucky and West Virginia. The virtually unexplored deep Moorman Syncline in western Kentucky appears to have significant potential for major gas production.

Information Circulars

IC 43. *Available Coal Resources of the Handshoe 7.5-Minute Quadrangle, Knott County, Kentucky*, by Gerald A. Weisenfluh, Robert E. Andrews, John K. Hiett, and Richard E. Sergeant, 45 p.

Results from this study indicate that 12 coal beds in the Handshoe Quadrangle have the potential to be mined. Taking into consideration the various restrictions to mining, geographic information system (GIS) methods were used to calculate estimates of original, mined-out, and remaining resources for the 12 coal beds in this quadrangle.

IC 44. *Quality of Private Ground-Water Supplies in Kentucky*, by Daniel I. Carey, James S. Dinger, O. Barton Davidson, Richard E. Sergeant, Joseph L. Taraba, Thomas W. Ilvento, Steve Coleman, Rayetta Boone, and Laura M. Knoth, 155 p.

Approximately 720,000 Kentuckians rely on private ground-water systems for their drinking water and water for livestock and irrigation of crops. Not all ground water is safe or pleasant to drink. Most studies of ground water have focused on areas of high vulnerability to pollution, and thus have exaggerated the extent of ground-water contamination. Because information about "typical" private water supplies has been scarce, the Ground Water Education and Testing Program surveyed selected well owners in all but 12 counties of the State. The survey asked four general questions: (1) What kind of well is it? (2) How is it used? (3) Where is the well located in relation to crops, chemicals, livestock, waste, and other potential sources of pollution? (4) What is the quality of the water? Results of the survey are presented in five tables and three appendices. Preliminary summaries suggest regional differences in ground-water quality. This report is a starting point for evaluating local and regional ground-water quality based on the natural environment and human activities, and should serve as a guide for further study and the development of rational ground-water management and protection activities.

IC 45. *Oil and Gas Drilling Activity Summary for Kentucky, 1992*, by Brandon C. Nuttall, 138 p.

This report presents production statistics for wells reported as having been completed during the calendar year 1992. Drilling activity in Kentucky remained relatively steady in 1992, with only a 2 percent decrease from 1991 levels to 1,270 reported well completions and a success rate of 66 percent. Leslie County continued to be the top oil-producing county in Kentucky with 1,077,775 barrels, or 20 percent of the total State production.

IC 46. *Impact of Riparian Grass Filter Strips on Surface-Water Quality*, by Alex W. Fogle, Daniel I. Carey, Billy J. Barfield, Robert L. Blevins, Vasilios P. Evangelou, Cora E. Madison, and Shreeram P. Inamdar, 14 p.

The effectiveness of strips of grass planted along stream banks for removing sediment and agricultural chemicals from surface runoff from planted fields was studied. Tests were performed using both no-tillage and conventional-tillage erosion plots. Runoff from the tillage plots was directed onto grass filter strips of varying lengths, and the inflow and outflow concentrations and sediment-size distributions were measured. Trapping efficiencies for sediment and agricultural chemicals were typically about 90 percent, mainly because of high infiltration rates. The grass filters also significantly reduced peak discharge concentrations, which reduced the impact of sediment and agricultural chemicals on receiving surface waters.

Map and Chart Series

MCS 5. *Structure on the Middle Ordovician High Bridge/Black River Group in the Tri-State Area of Northern Kentucky, Southwestern Ohio, and Southeastern Indiana*, by Paul Edwin Potter, 1 sheet.

Map and Chart Series 5 discusses the geology and geologic structure of the area under and adjacent to Cincinnati, Ohio. The High Bridge Group was selected as the mapping horizon because it is the highest practical regional unit that covers all of the tri-state area. It is also easily identified because of the marked lithologic contrast between the micritic limestone of the High Bridge and the overlying shelly limestones of the Lexington Limestone. This publication provides information useful for planning resource development, engineering geology, and studies of ground-water resources and flow direction.

MCS 6. *Oil and Gas Maps of the Pikeville 30 X 60 Minute Quadrangle, Kentucky*, by Dan Walker, Joseph F. Meglen, Brandon C. Nuttall, X. Mara Chen, and Anna E. Watson, 2 maps and 10-page text.

Map and Chart Series 6 consists of two maps and a brief text. The maps show the distribution of wells that have been drilled for oil and gas in the area, and outlines of producing fields and pools. Because the area has been extensively drilled in search of gas from the Devonian shales in what is known as the Big Sandy District, one map shows only these wells; the other map shows all fields and pools exclusive of the Big Sandy District. Detailed information about fields and pools, including specific pays, county, discovery date, Carter coordinate location, and previous pool names, is shown in an accompanying table.

Report of Investigations

RI 7. *Flooding of the Sinking Creek Karst Area in Jessamine and Woodford Counties, Kentucky*, by James C. Currens and C. Douglas R. Graham, 33 p.

Sinking Creek Karst Valley was flooded in February 1989. To determine the cause of flooding, the boundary of the ground-water basin was mapped, discharge data were measured to determine intake capacity of swallow holes, and hydrologic modelling of the basin was conducted. The results of these studies are presented in Report of Investigations 7. Swallow-hole capacity was determined to be limited by the hydraulic parameters of the conduit, rather than obstruction by trash or other causes of plugging. Hydrologic modelling indicates that further suburban development in the area will result in increased flooding at Tashamingo Subdivision.

Reprints

R 36. *Determination of Fluorine in Coal and Coal Fly Ash by Proton-Induced Gamma-Ray Emission Analysis*, by A.S. Wong, J.D. Robertson, and H.A. Francis, 12 p.

R 37. *The Mineral Industry of Kentucky, 1991*, by L.J. Prosser, Jr., and G.R. Dever, Jr., 7 p.

R 38. *Stratigraphic Effects of the Acadian Orogeny in the Autochthonous Appalachian Basin*, by Terence Hamilton-Smith, 12 p.

R 39. *Near-Surface Deformation in the New Madrid Seismic Zone as Imaged by High-Resolution SH-Wave Seismic Methods*, by Edward W. Woolery, Ron L. Street, Zhenming Wang, and James B. Harris, 4 p.

R 40. *"Pipe-Organ Structures" in the Lee Formation (Pennsylvanian) of the Central Appalachian Basin: Animal or Plant?*, by Donald R. Chesnut, Jr., James C. Cobb, and Stephen F. Greb, 9 p.

R 41. *Reptile Trackway from the Lee Formation (Lower Pennsylvanian) of South-Central Kentucky*, by Donald R. Chesnut, Jr., Donald Baird, J.H. Smith, and R.Q. Lewis, Sr., 5 p.

Special Publication

SP 19. *Fossil Beds of the Falls of the Ohio*, by Stephen F. Greb, Richard Todd Hendricks, and Donald R. Chesnut, Jr., 39 p.

Special Publication 19 describes the geology of one of the best exposed areas of Devonian-age fossils in the world. The main purpose of the new publication is to acquaint students and others with the geologic history of the Falls area and describe many of the fossils that can be found there. The report is richly illustrated with drawings by Stephen Greb, and one of Dr. Greb's acrylic paintings depicting life on the Devonian seafloor was used on the front cover. This painting was also reproduced on the front cover of the March 1994 issue of *Geotimes*.

Thesis Series

TS 5. *Ground-Water Geochemistry and Its Relationship to the Flow System at an Unmined Site in the Eastern Kentucky Coal Field*, by David R. Wunsch, 128 p.

Thesis Series 5 documents the occurrence, movement, and chemistry of ground water in an area in Perry County, Kentucky, that has not been disturbed by surface mining of coal. This study, which is the result of a doctoral dissertation at the University of Kentucky, investigates the relationship between ground-water chemistry and the flow system that controls the movement of ground water. Relatively high levels of naturally occurring fluorine and barium were detected in the ground water. Documenting the current levels of ground-water constituents in an area that has not been disturbed by mining or other operations provides baseline information that can be used for comparison purposes to recognize possible impacts of various activities in the future.

TS 6. *Conceptual Model of Local and Regional Ground-Water Flow in the Eastern Kentucky Coal Field*, by Shelley A. Minns, 194 p.

Understanding the ground-water flow system in the Eastern Kentucky Coal Field is very important for developing effective ground-water monitoring networks for mining operations and other surface or underground disturbances. This report, prepared as a doctoral dissertation at the University of Kentucky, is based on information obtained from an ongoing project in Leslie County to determine the effects of deep mining on the ground-water system, as well as data from previous studies in the area. Core-hole data, information from

pressure-injection tests, water-quality data, and water-level information were used to identify three zones on the basis of their hydraulic properties. The shallow-fracture zone, an intensively fractured, blanket-like layer that extends from the surface to a depth of about 70 feet, is perhaps the most important zone because most of the domestic water wells in eastern Kentucky produce from this interval. The conceptual model of ground-water flow indicates that local flow systems develop in the shallow-fracture zone. Regional flow is from upland areas toward the larger streams. Chemical analysis of the ground water suggests that water types in the regional system differ above and below the Magoffin beds of the Breathitt Formation.

Miscellaneous

KGS Annual Report, 1992–1993, 58 p.

Status of the Topographic Mapping Revision Program in Kentucky (September 1, 1993), 1 sheet.

Fact Sheets: Coal, Water, Oil and Gas, Industrial Minerals, Limestone, and Fossils.

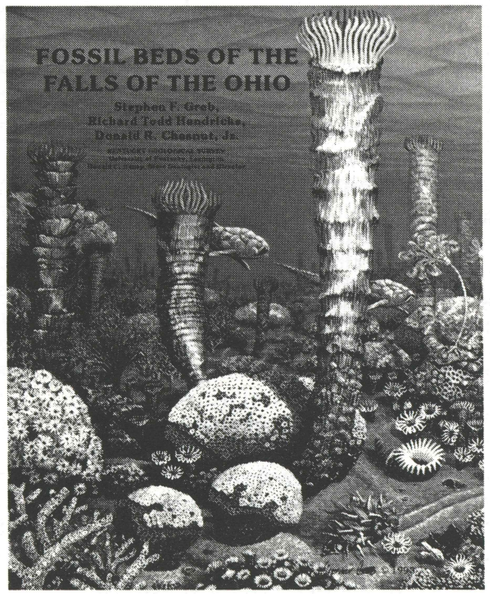
Cooperative Topographic Mapping

The Kentucky Geological Survey has participated in an ongoing cooperative program with the U.S. Geological Survey for topographic map revision in the State since Kentucky became the first major state to be entirely mapped topographically at a scale of 1:24,000 more than 35 years ago. This program is designed to maintain revised and up-to-date maps for all areas of the Commonwealth.

Revision of the Elizabethtown Quadrangle in 1991 marked the first topographic map in Kentucky to be reproduced from digital data. This quadrangle was completely revised.

Thirty-six newly revised 7.5-minute-quadrangle topographic maps were received from the U.S. Geological Survey during the 1993–94 fiscal year. One of these maps, the Bethlehem Quadrangle, was a standard update; it was field checked and limited revision of contours took place. The remaining maps were limited updates, which involve making changes that can be observed on aerial photographs, but no contours are changed and no field checking is done. The updated maps were the Adams, Bangor, Berea, Blaine, Cannel City, Coletown, Delaplain, Ezel, Fallsburg, Fisherville, Ford, Frankfort East, Frankfort West, Georgetown, Hazel Green, Henderson, La Grange, Lexington East, Lexington West, Little Hickman, Louisa, Madrid, Mays Lick, Millerstown, Nicholasville, Richmond North, Shelbyville, Taylorsville, Upton, Waterford, West Liberty, Wilson, Winchester, and Wrigley Quadrangles.

A map showing the status of the topographic mapping revision program is available from the Kentucky Geological Survey free upon request.



PUBLIC SERVICES

Coal and Minerals Section

EARTH SCIENCE EDUCATIONAL MATERIALS

"Rocks and Minerals of Kentucky," a new book that includes color photographs and descriptions of various rocks and minerals of Kentucky, will be published by the end of 1994 in the Special Publication series. This book details most of the minerals that occur in the State, from the common calcite crystals, to the rare millerite and Kentucky agate. It will be of interest to all rock collectors and scientists who want a reference book on Kentucky rocks and minerals. An accompanying slide set of the minerals will also be made available for educational purposes.

A sample set of three rocks and minerals is still made available upon request at no charge to schools, scouts, and hobby collectors. The staff of KGS also provides assistance in identifying rocks, minerals, and fossils. New display cases are being constructed that will be placed in the second-floor lobby of the Mining and Mineral Resources Building. These new cases will display many types of rock and fossil specimens, and will be a great educational asset for visiting school groups.

PUBLIC ACCESS TO COAL INFORMATION AND COAL-DATA MANAGEMENT

The most important mission of the Kentucky Geological Survey is to provide information to the public on mineral resources. Coal information is made available through formal publications, open-file reports, presentations to groups, and computerized data bases. The Kentucky Coal Resources Information System (KCRIS) was established to provide coal-related data to the public. KCRIS contains computerized and open-file coal-quality, thickness, resources, core-description, and coal-related engineering data. These data have been collected by the Survey for the last two decades, and the data bases are continually being updated with new information resulting from KGS research projects. Analytical data from the KGS Coal Laboratory are added to the data base as well.

KGS personnel work continuously to code and enter data into the computer system, and KGS geologists travel throughout the State to sample coal beds, measure coal-bearing outcrops, collect core descriptions, and describe core. All coal data must be located stratigraphically, topographically, and geographically before they can be entered into the data base.

Petroleum and Stratigraphy Section

In addition to its research responsibility, the Petroleum and Stratigraphy Section provides services relating to the exploration for and development of oil and gas resources.

OIL AND GAS WELL RECORDS

The Petroleum and Stratigraphy Section is responsible for the oil

Assistant State Geologist John Kiefer hands out mineral specimens at the National Science Teachers Association regional convention in Louisville, Kentucky.

and gas well records stored in the newly developed Geologic Data Center at the Survey; KGS is the official repository for records for all oil and gas wells drilled in the State. A variety of records, such as drillers' logs, wireline logs, well-location survey plats, plugging affidavits, and completion reports, are on file for an estimated 225,000 wells. In addition, data for wells in western Kentucky are also available at the Henderson office.

Records for 1,375 new wells were processed and recorded by the Survey last year. The Kentucky Geological Survey staff also reviews and enters into the computerized data base as many of the older well records as time permits; nearly 2,210 older records were added to the data base in 1993. The computerization of the well records and the expanded utility of supporting data sets are expected to greatly enhance the speed and efficiency of data retrieval. By the end of 1994, data for approximately 110,000 wells should be electronically available.

Last year, 1,991 visitors were assisted and 1,708 phone requests for oil and gas information were processed at the Lexington and Henderson facilities. A total of 25,615 copies of well records were supplied. A new Xerox 2515 engineering copier was leased for copying continuous well logs, including electrical, mechanical, nuclear, and geophysical logs. More than 38,000 feet, representing logs for more than 2,900 wells, were copied for the public in 1993.

Custom printouts based on user specifications can be made on request. Well-location base maps are available as overlays for the U.S. Geological Survey 1:24,000-scale 7.5-minute topographic quadrangle maps. Data are also available in machine-readable form on floppy disks. A total of 140 well lists, 644 computer-generated overlays to topographic maps, and 73 floppy diskettes were made in 1993.

The criteria for including wells in the data base has shifted from geographic areas to stratigraphic significance. Stratigraphic tops data entry continues for the Cambrian and deeper penetrations. Ordovician Knox and Pencil Cave bentonite tops for 123 wells in south-central Kentucky were entered in 1993.

For those areas not completed, the following well locations are available for plotting: all wells reported complete since January 1, 1981; all locations for which a permit has been issued since January 1, 1984; all pre-Trenton wells; all Devonian and deeper wells of western Kentucky and the majority of eastern Kentucky; and all Class II (injection and disposal) wells reported active in 1979 and completed since.

OIL AND GAS WELL-RECORD PRESERVATION

Since the oil and gas well-record files of the Kentucky Geological Survey are used extensively by the public and staff members, the paper files are deteriorating rapidly, and it has become evident that the files must be made available by some alternate method. In order to protect the original paper files from destruction by continual use, fire, and theft, and to make them simultaneously more accessible to Survey staff, industry, government representatives, and the general public, the individual well records are being optically scanned, and their raster images are being stored on magnetic tape. These images include available petrophysical logs.

To date, records for 32,541 wells have been scanned, resulting in one of the largest data bases of its kind in the country. In 1991, records selected for scanning were ranked based on stratigraphic significance to better meet increasing research and public demands. There were 13,436 documents scanned in 1993 for 3,551 wells.

During the year the scanning equipment failed, resulting in an opportunity to re-evaluate the project and formulate plans to enhance processing of documents. A procedure to generate bar codes for document identification and indexing was proposed. Equipment and software for printing and reading bar codes is currently on order. Bar codes will be assigned to each page of each document that is to be scanned. The bar-coded information will be used to appropriately index each image and automatically generate unique file specifications for image storage.

In addition, strategies for accelerating the scanning operation are being examined. The initial emphasis is to develop document processing, indexing, and scanning procedures utilizing oil and gas well record data that are already electronically cataloged. The procedures will then be extended to data not currently stored on the computer, including additional oil and gas well records, ground-water and water-well information, coal records, and industrial-mineral data.

WELL SAMPLE AND CORE REPOSITORY

KGS assists professionals and the general public using the information available at the Well Sample and Core Repository as they study the surface and subsurface geology of Kentucky. The Repository provides easy accessibility and permanent central storage for all well samples and cores obtained in Kentucky. Currently, more than 17,000 sets of well cuttings and 1,480 cores are on file in the facility. Well samples and cores

are cataloged, processed, and stored at the Repository. These materials are the greatest single source of subsurface information available for coal, mineral, and petroleum exploration. A computerized index to all cores available for public use at the KGS core repository was completed during the year. A catalog was prepared that contains information on 875 cores from 91 different counties.

During the year, more than 977 individual inquiries for information were answered by phone, and 245 persons visited the facility. The staff provided information to 91 persons. Numerous tours of the facility were provided to interested groups and individuals. Academia and industry are encouraged to use the Repository for research. About 70 visitors were assisted in identifying stratigraphic contacts in rock cores and cuttings. In addition, 130 samples from well cuttings and cores from 11 wells were sampled. More than 300 copies of information were provided to the public.

Over 65,000 feet of well samples were processed and added to the collection at the Repository. More than 6,600 boxes of core were sorted and inventoried, and 1,390 boxes of core were repaired. In addition, 3,395 feet of core were reboxed and 6,646 boxes of cores were sorted and shelved onto pallet racks.

Seventeen collection stations are located Statewide and are visited regularly to collect samples and meet representatives of industry. This interaction helps to maintain good working relationships between industry and researchers at KGS. Three of the collection stations were relocated. One was moved from Paintsville to Pineville. The other two were moved to new locations in Hazard and Owensboro.

At KGS's request, companies and government agencies donated 315 cores and well cuttings, representing more than 500,000 feet of vertical drilling to the Repository. In addition, 243 sets of well cuttings were added to the collection as required under the terms of oil and gas drilling permits. Seven cores donated by Exxon Minerals, representing over 2,400 feet of vertical drilling, were retrieved from a warehouse in Evansville, Indiana.

Because of the extensive damage suffered in the June 1992 flood, several methods of storing well cuttings were evaluated. New waterproof envelopes and boxes are being developed. Personnel at Northeast Document Conservation Center were contacted concerning techniques and procedures for separating well-sample envelopes damaged by the June 1992 flood. Various methods of separating damaged envelopes without destroying the samples were investigated. Insurance funds from flood claims were made available for purchasing supplies, equipment, and hiring additional personnel.

DEVELOPMENT OF FACILITIES AT THE KGS WELL SAMPLE AND CORE REPOSITORY—AMERICAN BUILDING

In June 1992 the entire KGS Well Sample and Core Repository was flooded. The Repository sustained tremendous damage, and KGS submitted an insurance claim of $430,000. About 630,000 envelopes containing samples of well cuttings stored in 4,550 boxes were damaged beyond repair; this amount represents one-sixth of the entire collection, and resulted in a setback of several years' work. In addition, approximately 1,200 core boxes were damaged, along with publications, maps, equipment, supplies, books, and two vehicles.

The facility is not yet in full operation, although it has been reopened for public use. Future renovation and new construction is uncertain. However, refurbishment of the facility began in February 1994. Materials damaged by the flood are being restored, and storage racks are being constructed. Full restoration of the facilities and all holdings will continue, pending a firm decision on whether to renovate the existing facility or build a new one.

Publications Section

PUBLICATION SALES AND DATA DISTRIBUTION

The Publication Sales Office of the Kentucky Geological Survey makes published information about Kentucky's mineral and water resources available to thousands of customers each year. Maps and reports published by the Kentucky Geological Survey and U.S. Geological Survey account for most of the materials sold, but publications from other sources, as well as open-file reports dealing with Kentucky geology, are also available.

The Publication Sales Office is located on the first floor of the Mining and Mineral Resources Building at the corner of Rose Street and Clifton Avenue on the University of Kentucky campus. Convenient parking for customers is located in the University of Kentucky Faculty Club parking lot behind the Mining and Mineral Resources Building.

The office stocks 7.5-minute-quadrangle topographic and geologic maps for the entire State. These maps are at a scale of 1:24,000 (1 inch on the map represents 2,000 feet on the ground) and depict in great detail Kentucky's

topography and geology. All available 1:250,000- and 1:100,000-scale topographic maps of Kentucky, as well as complete coverage of Hydrologic Atlases and a number of 7.5-minute-quadrangle flood-prone-area maps published by the U.S. Geological Survey are also kept in stock. In addition, numerous other geologic, geophysical, structure, hydrologic, and mineral-resource maps are available from the KGS sales office. Open-file maps showing landslides and related features are available for approximately 250 quadrangles in eastern and south-central Kentucky; copies of these maps are available at a nominal cost.

All KGS reports that are still in print and USGS reports that deal with Kentucky geology are available for purchase at the Publication Sales Office. In addition, KGS maintains an extensive collection of open-file materials, including reports and maps, which can be reproduced for customers at a nominal charge.

The Publication Sales Office handles a large volume of requests for maps and reports. During the past fiscal year, this office distributed approximately 22,500 maps and 3,700 reports, as well as 20,600 copies of well records and other miscellaneous items. Most mail orders are shipped out the day after they are received.

A List of Publications, which shows available maps and reports and gives complete ordering instructions, is available free upon request.

EARTH SCIENCE INFORMATION CENTER

The Kentucky Geological Survey–Earth Science Information Center (KGS–ESIC) answers inquiries regarding the availability of current and historic map information, aerial photography, satellite imagery, geodetic control, and digital cartographic data. The office also answers questions about the availability of all types of earth-science information in Kentucky. The KGS–ESIC office is located in Room 104A on the first floor of the Mining and Mineral Resources Building adjacent to the KGS Publication Sales Office.

Resources available to the KGS–ESIC office for answering requests include a file of more than 5,700 microfiche indexes to aerial photography (available also on CD-ROM), satellite data (with an up-to-date, micro-image index), and historic maps (a microfilm file containing 37,400 historical topographic maps of the United States). Access to the USGS electronic data base of geographic names (GNIS) for Kentucky, which contains more than 30,000 place names used on Kentucky topographic maps, is available. Also, information is available about how to contact various USGS agencies for geophysical data, seismic data, gravity-anomaly information, magnetic data, and navigational information from the U.S. Army Corps of Engineers and Tennessee Valley Authority.

Close coordination between KGS–ESIC and the KGS Publication Sales Office makes it possible for many persons to obtain desired materials or information as the result of a single inquiry or visit to the Kentucky Geological Survey. However, in some cases it may be necessary to refer persons to another State or Federal agency, or private firm, as the source for a particular product.

Almost 600 individual inquiries for information were answered by KGS–ESIC during the 1993–94 fiscal year. Of these requests, 35 percent were for map-related information, 38 percent were for geodetic control data, 12 percent were for aerial photography or space imagery, 3 percent concerned digital map products, and 12 percent were for information about available publications. Ordering assistance to obtain the desired materials was provided for many of the requests.

During the year, the KGS–ESIC representative participated in numerous activities to help make earth-science information available to the public. These activities included making presentations about topographic maps to students and professional groups, and working with the State Mapping Advisory Committee.

Water Resources Section

The Water Resources Section provides daily consultation to the public on both water quality and quantity. During the past year the Section answered approximately 500 requests for surface- and ground-water information.

Most requests can be answered through a search of available literature and maps, although a field visit may be made when necessary. Although manpower limitations prevent extensive field investigations, these investigations frequently provide valuable data for KGS as well as for the person making the request.

THE KENTUCKY GROUND-WATER DATA REPOSITORY

The Kentucky Ground-Water Data Repository was created in 1990 by the Kentucky Geological Survey under mandate from the Kentucky General Assembly (KRS 151:035). The purpose of the Repository is to archive and disseminate ground-water data collected by State agencies, other organizations, and independent researchers. Prior to the initiation of the Repository, ground-water data were housed at many different locations throughout the State. The intent of the Repository is to provide public service at a centralized location to anyone requiring ground-water data from Kentucky.

The computerized component of the Repository is the Kentucky Hydrologic Data Base. This comprehensive, interactive data base includes information on ground water from all areas of the Commonwealth. These data have been generated from over 15 different sources.

Also included in the Repository are hard-copy map files, field notes, ground-water publications, and other related information. Efforts are underway to compile ground-water data from State agencies and other sources in the industrial, academic, public health, and research sectors. This task will be an ongoing goal of the Repository as new ground-water data are generated.

The Repository responded to 460 public inquiries during the year. Approximately 70 percent of these inquiries dealt with environmental issues. The remaining 30 percent were general inquiries from both the public and private sectors concerning ground-water occurrence, supply, and quality. Use of the Repository has increased substantially this year, and should continue to grow as more Kentuckians become aware of the information and services provided by the Repository.

THE KENTUCKY HYDROLOGIC DATA BASE

The Kentucky Hydrologic Data Base is the computerized component of the Kentucky Ground-Water Data Repository, and is a comprehensive source of ground-water information for the State. Types of data included in the Hydrologic Data Base are information on water wells, well construction, water quality, springs, dye traces, discharge and water level, and lithology derived from well logs. To date, the data base contains 27,000 unique site records. This number will continue to increase as new data from various State agencies and other contributors are added to the data base.

The Hydrologic Data Base is dynamic, and is constantly being updated, modified, and expanded to meet the growing demand for ground-water information from industry, university researchers, State and Federal agencies, and the general public. Data from the Hydrologic Data Base are disseminated to the public on various media, including hard-copy printouts, magnetic tapes of several different types, and diskettes. Efforts to provide on-demand electronic publications such as computer-generated maps and data summaries are under way.

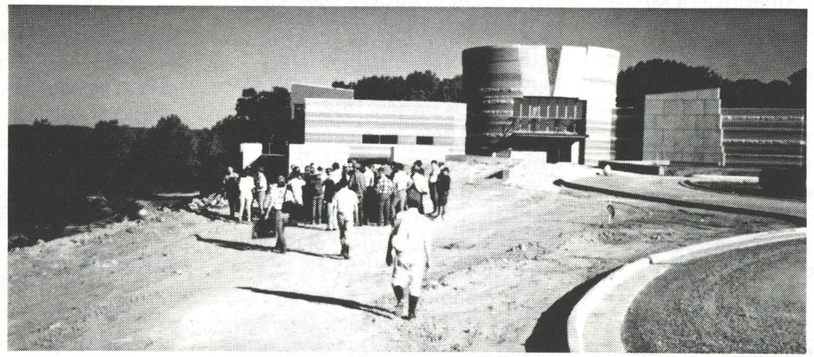
GROUND-WATER DYE TRACE DATA BASE AND KARST GROUND-WATER BASIN ATLAS

This cooperative project with the Kentucky Division of Water has proceeded as time permits, without additional funding, for the past 2 years. Tracing data, such as injection and recovery location and dates, will be summarized in a listing that will accompany basin maps, providing the first Statewide delineation of karst basins in Kentucky. The value of such maps and data for water-supply determination, ground-water protection, and general economic development is signficant.

SURFACE-WATER DATA BASE

A surface-water data base for Kentucky continues to be expanded for use in research and to provide data for public inquiries. With this information now available to them through the KGS data bases, users can obtain geologic, topographic, and surface- and ground-water data in a centralized location. Providing easily accessible data in a centralized location will increase efficiency and encourage greater utilization of data by consultants, agencies, local governments, and citizens groups.

Currently, the surface-water data base includes flow and water-quality data. Low-flow and flood statistics will be incorporated on a priority basis.



Participants in the Geological Society of Kentucky 1993 Field Trip approach the Visitors Center at the Falls of the Ohio State Park near Louisville.

KENTUCKY GEOLOGICAL SURVEY DISTINGUISHED LECTURE SERIES

The Distinguished Lecture Series was begun in 1988 to commemorate former State Geologists of Kentucky. The first lectures were held in conjunction with the Kentucky Geological Survey's sesquicentennial celebration and honored William W. Mather, Kentucky's first State Geologist. Sesquicentennial Distinguished Lecturers were William L. Fisher, "Oil and Gas Research: Opportunities and Challenges"; Harold J. Gluskoter, "Coal Geology: Who Is Mining the Store?"; Philip Cohen, "Ground-Water Situation in the United States"; Allen F. Agnew, "Industrial Minerals and Rocks—Who Needs Them?"; and Charles J. Mankin, "The Role of Geology in Shaping Public Policy."

The second Distinguished Lecture, in honor of David Dale Owen, was presented in 1989 by Hermann W. Pfefferkorn, whose topic was "The Orinoco Delta in Tropical South America as a Model for Coal-Bearing Strata in the United States." Aureal T. Cross presented the Nathaniel S. Shaler Distinguished Lecture in 1991; the title of his presentation was "Aspects of Plants in Coal and the Coalification Process." In 1992, Paul Edwin Potter was chosen as the John R. Procter Distinguished Lecturer in honor of Kentucky's fourth State Geologist. The title of Dr. Potter's lecture was "Contributions to Sedimentology—Geology from the North American Heartland." The 1993 KGS Distinguished Lecture honored Dr. Wallace W. Hagan, who retired as State Geologist and Director of the Kentucky Geological Survey in 1978. The presentation was made by Philip E. LaMoreaux, who spoke on "The Importance of Environmental Geology."

In 1994 the Charles Joseph Norwood Distinguished Lecture was presented by Robert D. Hatcher, Jr., whose topic was "The Impasse over Disposal of Hazardous and Radioactive Waste, and Environmental Degradation—Political Juggernaut or Opportunity for Geological Scientists?" Dr. Hatcher is Professor of Geology and Distinguished Scientist at the University of Tennessee and Oak Ridge National Laboratory, positions he has held since 1986. His major research interests include anatomy of mountain chains, polyphase deformation, development of mesofabrics, microstructure of mylonites, strain in thrust sheets, stratigraphy in metamorphic rocks, palinspastic reconstruction of mountain chains, and regional geophysics. His present research projects are all field based and involve a major component of geologic mapping. Dr. Hatcher's employment, in addition to teaching, has included a wide variety of consulting projects for mineral-exploration companies, engineering firms, and government agencies. He has served as President of the Geological Society of America and was the first recipient of the GSA Distinguished Service Award. Dr. Hatcher presently serves on several important national committees.

The 1994 Distinguished Lecture was in honor of Charles Joseph Norwood, who was Kentucky's fifth State Geologist and served as Director of the Kentucky Geological Survey from 1904 to 1912. Prior to assuming this position, he served as State Inspector of Mines and Dean of the College of Mining Engineering at the University of Kentucky. Under Norwood's leadership, the Kentucky Geological Survey focused its efforts on studying the economic geology of the State, and during the 8-year period while he was Director the Survey issued 27 publications dealing with the natural and mineral resources of Kentucky.

Distinguished Lectures

William W. Mather—1988
William L. Fisher
Harold J. Gluskoter
Philip Cohen
Allen F. Agnew
Charles J. Mankin

David Dale Owen—1989
Hermann W. Pfefferkorn

Nathaniel S. Shaler—1991
Aureal T. Cross

John R. Procter—1992
Paul Edwin Potter

Wallace W. Hagan—1993
Philip E. LaMoreaux

Charles Joseph Norwood—1994
Robert D. Hatcher, Jr.

COMMITTEES, BOARDS, AND ADVISORY ACTIVITIES

International

Global Sedimentary Basins Stress Project
Terence Hamilton-Smith.

National

American Association of Petroleum Geologists
James C. Cobb—Counselor. James A. Drahovzal—Delegate of the Geological Society of Kentucky to the House of Delegates; Chairman, Eastern Section Membership Committee; Research Committee. Donald C. Haney—Representative of the Association of American State Geologists. David C. Harris—Eastern Section Membership Committee.

American Geological Institute
James C. Cobb—Chair, *Geotimes* Editorial Committee. Donald C. Haney—Past-President; AGI Foundation.

American Society for Testing and Materials
Cortland F. Eble—Task group leader for updating microscopic standards for coal. Henry E. Francis—Subcommittee D-5 on Coal and Coke; Subcommittee D-19 on Water; Subcommittee E-11 on Quality and Statistics; Subcommittee E-36 on Laboratory Accreditation.

Appalachian Oil and Natural Gas Research Consortium
James A. Drahovzal—KGS Research Coordinator. Terence Hamilton-Smith—Potential Gas Committee.

Association of American State Geologists
Donald C. Haney—Chairman, Cooperative Planning Committee.

Central Appalachian Alliance
James C. Cobb.

Central United States Earthquake Consortium
John D. Kiefer—State Geologists Committee.

Digital Equipment Computer Users Society
Steven J. Cordiviola—Chairman, Communications and Information Products Unit.

Eastern Oil Shale Symposium
Terence Hamilton-Smith—Technical Advisory Committee; Chairman, Heavy Oil Sands Subcommittee.

Editorial Board of the Journal *Ground Water*
James A. Kipp—Auxiliary Member.

Energy Advisory Board
Donald C. Haney—Secretary, Fuel Cycle Peer Review Panel.

Geological Society of America
James A. Drahovzal—Committee on Nominations. Cortland F. Eble—Secretary/Treasurer of the Coal Geology Division. Donald C. Haney—Chairman, Geology and Public Policy Committee; Chairman, Southeastern Section. John D. Kiefer—Southeastern Section Committee on Geology and Public Policy.

Geology Alumni Advisory Board for the Department of Geology, University of Iowa
James A. Drahovzal.

Illinois Basin Consortium
James A. Drahovzal—Chairman; KGS Research Coordinator; Seismic Task Force Advisor.

Interstate Oil and Gas Compact Commission
John D. Kiefer—Environmental Affairs Committee.

National Academy of Science
Donald C. Haney—Executive Committee; Board on Earth Science and Resources; Committee on Mineral Resources.

National Research Council
Donald C. Haney—Board on Earth Sciences and Resources.

National Stone Association
Garland R. Dever, Jr.—Program Committee for 1993 SO_2 Capture Conference.

Ohio River Basin Consortium for Research and Education
John D. Kiefer—Board of Directors; Representative for the University of Kentucky.

U.S. Department of Energy
James C. Cobb—Committee on Coal Resources.

U.S. Geological Survey
James C. Cobb—Volunteer Associate Scientist.

U.S. Secretary of the Interior's National Geologic Mapping Advisory Committee
Donald C. Haney.

State

Geological Society of Kentucky
O. Barton Davidson—Treasurer, 1993-94. David C. Harris—President, 1993. Shelley A. Minns—Eastern Vice President, 1994. Richard A. Smath—Secretary, 1994.

Governor's Council on Nonpoint Source Pollution
Donald C. Haney.

Governor's Earthquake Hazards and Safety Technical Advisory Panel
John D. Kiefer—Chairman, Technical Subcommittee.

Governor's Geographic Information Advisory Council
Donald C. Haney.

Governor's Groundwater Advisory Council
Donald C. Haney. James S. Dinger—Chairman, Data Management Committee; Groundwater Monitoring Committee. James C. Currens—Data Management Committee. Richard E. Sergeant—Data Management Committee. James A. Kipp—Groundwater Monitoring Committee.

Kentucky Board of Registration for Professional Geologists
Donald C. Haney.

Kentucky Cabinet for Economic Development
James C. Cobb—Committee on Post-Mining Land Use.

Kentucky Department of Mines and Minerals, Division of Oil and Gas, Oil and Gas Issues Work Group
James A. Kipp.

Kentucky Engineering Earthquake Response Team
Daniel I. Carey.

Kentucky Groundwater Management Data Committee
O. Barton Davidson, Richard E. Sergeant.

Kentucky Information Systems Committee
Steven J. Cordiviola—Special Committee on Imaging; Geographic Information Systems Advisory Council. Donald C. Haney—Geographic Information Systems Advisory Council. Richard E. Sergeant—Chairman, Base Map Subcommittee of the Geographic Information Systems Advisory Council.

Kentucky Museum of Natural History
Donald R. Chesnut, Jr.—President, Board of Directors.

Kentucky Oil and Gas Association
John D. Kiefer—Technical Support Committee to the Hazardous Waste Disposal Task Force.

Kentucky On-Site Sewage Disposal Advisory Committee
James A. Kipp.

Kentucky Options 2000
John D. Kiefer—Technical Committee.

Kentucky River Authority
Donald C. Haney. Daniel I. Carey—Policies and Procedures Subcommittee; Water Quality Subcommittee.

Kentucky Stratigraphic Nomenclature Committee
Donald R. Chesnut, Jr., Stephen F. Greb, Garland R. Dever., Jr.

Kentucky Water Availability Advisory Council
James S. Dinger.

Kentucky Water-Well Drillers' Certification Board
James S. Dinger.

NORM Task Force
James A. Drahovzal, Terence Hamilton-Smith.

Tri-State Correlation Committee
Cortland F. Eble, Stephen F. Greb, David A. Williams.

University

Building Naming Committee
Donald C. Haney.

College of Agriculture Nonpoint-Source Assessment Advisory Committee
James S. Dinger.

Department of Agricultural Engineering
Daniel I. Carey—Adjunct Assistant Professor.

Department of Geological Sciences
James C. Cobb, James S. Dinger, James A. Drahovzal, Donald C. Haney—Adjunct Associate Professors.

Environmental System Committee
James C. Cobb—Program Coordinator. Donald C. Haney.

Groundwater Center Committee
Donald C. Haney.

Kentucky Center for Energy Research Advisory Board
Donald C. Haney.

Research and Graduate Studies Ad Hoc Committee for Business Policies/Procedures
John D. Kiefer.

United Way Cabinet
James C. Cobb.

Local

Cave Hollow Cave Gating Project
Tammie J. Heazlitt.

Lexington-Fayette Urban County Government Greenspace Commission
John D. Kiefer.

Lexington-Fayette Urban County Government McConnell Springs Restoration Committee
John D. Kiefer.

Lexington-Fayette Urban County Government Storm-Water Committee
John D. Kiefer.

Mammoth Cave Archaeological Survey
Tammie J. Heazlitt.

Mammoth Cave Karst Area Water-Quality Oversight Committee
James C. Currens.

National Speleological Society, Blue Grass Grotto
James C. Currens—Director.

Public Relations Committee for Kentucky Museum of Natural History
Tammie J. Heazlitt.

PAPERS BY STAFF MEMBERS IN OUTSIDE PUBLICATIONS

Baranoski, M.T., and **Harris, D.C.**, 1994, Play 32: Pre-Knox (Cambrian) structural and stratigraphic plays [abs.]: Program and Abstracts of the Twenty-Fifth Annual Appalachian Petroleum Geology Symposium, Morgantown, West Virginia: West Virginia Geological and Economic Survey, I.C. White Memorial Fund Publication 6, p. 4.

Barfield, B.J., **Fogle, A.W., Carey, D.I.,** Inamdar, S.P., Blevins, R.L., Madison, C.E., and Evangelou, V.P., 1993, Water quality impacts of natural riparian grasses: Part I. Empirical studies: University of Kentucky Water Resources Research Institute Research Report 184, 107 p.

Brauckmann, Carsten, **Chesnut, D.R., Jr.**, and Jennings, J.R., 1993, New spilapterid insect from the Breathitt Formation (Middle Pennsylvanian, Westphalian B) of eastern Kentucky, USA: Neues Jahrsbuch fur Geologie und Paleontologie, v. 11, p. 641–647.

Carey, D.I., Dinger, J.S., Davidson, O.B., Sergeant, R.E., Boone, R., Coleman, S., Ilvento, T., and Taraba, J., 1993, Quality of domestic well water in Kentucky: Ohio River Basin Consortium for Research and Education, Ninth Annual Scientific Symposium, Program with Abstracts, unpaginated.

Cecil, C.B., Dulong, F.T., **Cobb, J.C.**, and Supardi, 1993, Allogenic and autogenic controls on sedimentation in the Central Sumatra Basin as an analogue for Pennsylvanian coal-bearing strata in the Appalachian Basin, *in* Cobb, J.C., and Cecil, C.B., eds., 1993, Modern and ancient coal-forming environments: Geological Society of America Special Paper 286, p. 3–23.

Chesnut, D.R., Jr., 1993, Eustatic and tectonic control of sedimentation in the Pennsylvanian strata of the Central Appalachian Basin, USA: Douzième Congrès International de la Stratigraphie et Géologie du Carbonifère et Permien, Buenos Aires, 22–27 Septembre 1991, Comptes Rendus, v. 2, p. 421–430.

Chesnut, D.R., Jr., Baird, Donald, Smith, J.H., and Lewis, R.Q., Sr., 1994, A reptile trackway from the Lee Formation (Lower Pennsylvanian) of south-central Kentucky: Journal of Paleontology, v. 68, no. 1, p. 154–158.

Chesnut, D.R., Jr., Cobb, J.C., and Greb, S.F., 1993, Cyclothems of the Central Appalachian Basin: A modern analog from Indonesia: Douzième Congrès International de la Stratigraphie et Géologie du Carbonifère et Permien, Buenos Aires, 22–27 Septembre 1991, Comptes Rendus, v. 2, p. 431–436.

Cobb, J.C., and Cecil, C.B., eds., 1993, Modern and ancient coal-forming environments: Geological Society of America Special Paper 286, 198 p.

Comer, J.B., Hasenmueller, N.R., Frankie, W.T., and **Hamilton-Smith, Terence**, 1993, Gas potential of the New Albany Shale (Devonian–Mississippian) in the Illinois Basin [abs.]: Abstracts, 1993 Eastern Oil Shale Symposium, Lexington, Kentucky: University of Kentucky Institute for Mining and Minerals Research and Center for Applied Energy Research, p. 71.

Comer, J.B., Hasenmueller, N.R., Frankie, W.T., and **Hamilton-Smith, Terence**, 1993, Gas potential of the New Albany Shale (Devonian–Mississippian) in the Illinois Basin [abs.]: American Association of Petroleum Geologists Bulletin, v. 77, no. 8, p. 1467.

Conrad, P.G., ed., 1993, Kentucky Museum of Natural History newsletter: Winter 1993, 7 p.

Conrad, P.G., Dinger, J.S., Sendlein, L.V.A., and Snell, J.D., 1993, Ground-water quality and agricultural practices at two sites in Pleistocene deposits of Kentucky [abs.]: Proceedings, Kentucky Water Resources Symposium, December 16, 1993, Lexington, Kentucky, p. 29.

Currens, J.C., and Graham, C.D.R., 1993, Flooding of Sinking Creek, Garretts Spring Karst Drainage Basin, Jessamine and Woodford Counties, Kentucky,

in Beck, B.F., ed., Applied karst geology: Proceedings, Fourth Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impact of Karst, A.A. Balkema, Rotterdam, p. 145–156.

Currens, J.C., and Graham, C.D.R., 1993, Flooding of Sinking Creek, Garretts Spring Karst Drainage Basin, Jessamine and Woodford Counties, Kentucky, USA: Environmental Geology, v. 22, no. 4, p. 337–344.

Davidson, O.B., 1993, The Kentucky Ground-Water Data Repository [abs.]: Ohio River Basin Consortium for Research and Education, Ninth Annual Scientific Symposium, Program with Abstracts, unpaginated.

Davidson, O.B., 1993, The Kentucky Ground-Water Data Repository [abs.]: Proceedings, Kentucky Water Resources Symposium, December 16, 1993, Lexington, Kentucky, p. 67.

Davidson, O.B., 1993, Kentucky's Ground-Water Data Repository centralizes resources: University of Kentucky Institute for Mining and Minerals Research *Highlights*, v. 12, no. 4, p. 2.

Dever, G.R., Jr., 1994, Kentucky, *in* 1993 annual review: Mining Engineering, v. 46, no. 5, p. 414.

Dever, G.R., Jr., and Teitloff, Terry, 1994, Vulcan Materials Company Reed Quarry, Livingston County, Kentucky, *in* Lasemi, Zakaria, Treworgy, J.D., Norby, R.D., Grube, J.P., and Huff, B.G., Waulsortian mounds and reservoir potential of the Ullin Limestone ("Warsaw") in southern Illinois and adjacent areas in Kentucky: Illinois State Geological Survey Guidebook 25, p. 56–57.

Drahovzal, J.A., 1994, Basin-floor fan complexes in Cambrian rift basins of Kentucky [abs.]: American Association of Petroleum Geologists 1994 Annual Convention, Denver, Colorado, Official Program, v. 3, p. 139.

Drahovzal, J.A., 1994, The structure, stratigraphy, and future hydrocarbon potential of the Rome Trough in Kentucky [abs.]: Program and Abstracts of the Twenty-Fifth Annual Appalachian Petroleum Geology Symposium, Morgantown, West Virginia: West Virginia Geological and Economic Survey, I.C. White Memorial Fund Publication 6, p. 33–38.

Drahovzal, J.A., and Wickstrom, L.H., 1993, The East Continent Rift Basin [abs.]: American Association of Petroleum Geologists, Hedberg Research Conference on Basement and Basins of Eastern North America, University of Michigan, Ann Arbor, Michigan, 2 p.

Eble, C.F., 1993, Coal quality variability of upper Raccoon Creek Group (Upper Tradewater) coal beds, Indiana: Indiana Geological Survey Open File Report 93-7, p. 19–20.

Eble, C.F., Calder, J.H., and Hower, J.C., 1993, A palynologic, petrographic and geochemical comparison of the Manchester coal bed (Central Appalachian Basin, USA), and the No. 3 coal bed (Cumberland Basin, Nova Scotia) [abs.]: Geological Society of America Abstracts with Program, v. 25, no. 6, p. 139.

Eble, C.F., and Grady, W.C., 1993, Palynologic and petrographic characteristics of two Middle Pennsylvanian coal beds and a probable modern analog, *in* Cobb, J.C., and Cecil, C.B., eds., Modern and ancient coal-forming environments: Geological Society of America Special Paper 286, p. 287–306.

Eble, C.F., Hower, J.C., and Andrews, W.M., Jr., 1994, Paleoecology of the Fire Clay coal bed in a portion of the Eastern Kentucky Coal Field: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 106, p. 287–306.

Fogle, A.W., and Barfield, B.J., 1993, A low head loss sampling device for monitoring inflow to natural vegetated filter strips: Transactions, American Society of Agricultural Engineers, v. 36, no. 3, p. 791–793.

Fogle, A.W., McBurnie, J.C., Barfield, B.J., and Robinson, K.M., 1993, Modeling free jet trajectory at an overfall and resulting shear stress distribution in a plunge pool: Transactions, American Society of Agricultural Engineers, v. 36, no. 5, p. 1309–1318.

Grady, W.C., **Eble, C.F.,** and Neuzil, S.G., 1993, Brown coal maceral distribution in a modern domed tropical Indonesian peat and a comparison with maceral distributions in Middle Pennsylvanian age Appalachian bituminous coal beds, *in* Cobb, J.C., and Cecil, C.B., eds., Modern and ancient coal-forming environments: Geological Society of America Special Paper 286, p. 63–82.

Greb, S.F., 1993, Peat accumulation in the Livingston Paleovalley (Morrowan), Central Appalachian Basin, *in* Archer, A., Feldman, H.R., and Linear, W.P., eds., Incised paleovalleys of the Douglas Group in northeastern Kansas and related contributions, Society of Economic Paleontologists and Mineralogists Midyear Meeting Field Trip: Kansas Geological Survey Open-File Report 9321, p. 15.1–15.6.

Greb, S.F., 1994, Devonian seafloor at the Falls of the Ohio [cover art]: Geotimes, v. 39.

Greb, S.F., 1994, Devonian seafloor at the Falls of the Ohio [cover art]: Rocks and Minerals, v. 69, no. 3.

Hamilton-Smith, Terence, 1994, Fractured Devonian shale gas reservoirs of the Appalachian Basin (Play 13/14) [abs.]: Program and Abstracts of the Twenty-Fifth Annual Appalachian Petroleum Geology Symposium, Morgantown, West Virginia: West Virginia Geological and Economic Survey, I.C. White Memorial Fund Publication 6, p. 41–44.

Harris, D.C., 1993, The Rose Run Sandstone in Kentucky: Is there potential south of the Ohio? [abs.]: Ohio Section, Society of Professional Well Log Analysts (SPWLA) Newsletter, November 1993.

Harris, J.B., Woolery, E.W., and Wang, Z., 1994, A shallow seismic investigation of Quaternary deformation on the Lake County Uplift, central New Madrid Seismic Zone [abs.]: Geological Society of America Abstracts with Programs, v. 26, no. 1, p. 8.

Hendricks, R.T., Ettensohn, F.R., Stark, T.J., and **Greb, S.F.,** 1993, Geology of the Devonian strata of the Falls of the Ohio area, Kentucky–Indiana—Stratigraphy, sedimentology, paleontology, structure, and diagenesis: Lexington, Geological Society of Kentucky, 53 p.

Hower, J.C., Graham, U.M., and **Eble, C.F.,** 1993, High sulfur coals in the Eastern Kentucky Coal Field: American Association of Petroleum Geologists Bulletin, v. 77, p. 1469.

Hower, J.C., **Eble, C.F.,** and Rathbone, R.F., 1994, No. 5 Block coal bed, northeastern Kentucky: International Journal of Coal Geology, v. 25, p. 171–193.

Humphreys, Matthew, and Watson, A.E., 1994, Middle Ordovician St. Peter Sandstone gas: Play 30 [abs.]: Program and Abstracts of the Twenty-Fifth Annual Appalachian Petroleum Geology Symposium, Morgantown, West Virginia: West Virginia Geological and Economic Survey, I.C. White Memorial Fund Publication 6, p. 52–54.

Ilvento, Tom, Taraba, Joe, Henken, Kim, and **Dinger, J.S.,** 1994, Groundwater education and well water testing program, summary of results: A special report from the Extension Water Quality Committee: University of Kentucky College of Agriculture, 8 p.

Inamdar, S.P., Barfield, B.J., **Carey, D.I., and Fogle, A.W.,** 1993, Water quality impacts of natural riparian grasses: Part II. Modeling effects of channelization on sediment trapping: University of Kentucky Water Resources Research Institute, Research Report 184, 88 p.

Meglen, J.F., and Noger, M.C., 1994, Lower Devonian–Upper Silurian unconformity play [abs.]: Program and Abstracts of the Twenty-Fifth Annual Appalachian Petroleum Geology Symposium, Morgantown, West Virginia: West Virginia Geological and Economic Survey, I.C. White Memorial Fund Publication 6, p. 62–63.

Meglen, J.F., Noger, M.C., Humphreys, Matthew, and Baranoski, M.T., 1994, Upper Silurian Lockport Dolomite–Keefer (Big Six) Sandstone play [abs.]: Program and Abstracts of the Twenty-Fifth Annual Appalachian Petroleum Geology Symposium, Morgantown, West Virginia: West Virginia Geological and Economic Survey, I.C. White Memorial Fund Publication 6, p. 64–67.

Nuttall, B.C., 1993, Annual review: Kentucky, 1992: Northeast Oil World, v. 13, no. 6, p. 12–13.

Nuttall, B.C., 1994, Play 28: The Upper Ordovician "Trenton" Limestone [abs.]: Program and Abstracts of the Twenty-Fifth Annual Appalachian Petroleum Geology Symposium, Morgantown, West Virginia: West Virginia Geological and Economic Survey, I.C. White Memorial Fund Publication 6, p. 71–72.

Nuttall, B.C., Hamilton-Smith, Terence, Humphreys, Matthew, Meglen, J.F., and Drahovzal, J.A., 1994, Natural gas resources of the Appalachian Basin region of eastern Kentucky [abs.]: American Association of Petroleum Geologists 1994 Annual Convention, Denver, Colorado, Official Program, v. 3, p. 176.

Pierce, B.S., **Eble, C.F.,** and Stanton, R.W., 1993, Petrography, palynology and paleobotany of the Little Fire Creek coal bed in southwestern Virginia, and implications for paleoenvironmental interpretations [abs.]: The Society for Organic Petrology Annual Meeting, v. 10, p. 28–30.

Pierce, B.S., Stanton, R.W., and **Eble, C.F.,** 1993, Comparison of petrography, palynology and paleobotany of the Stockton coal bed, West Virginia, and implications for paleoenvironmental interpretations: Organic Geochemistry, v. 20, no. 2, p. 149–166.

Prosser, L.J., Jr., and **Dever, G.R., Jr.,** 1993, The mineral industry of Kentucky: U.S. Bureau of Mines Minerals Yearbook, 1991, v. 2, p. 227–233.

Rutledge, J.T., Albright, J.N., Fairbanks, T.D., **Hamilton-Smith, Terence,** and Young, H.C., 1993, Subsurface fracture mapping using microearthquakes induced during primary oil production, Clinton County, Kentucky [abs.]: Abstracts, 1993 Eastern Oil Shale Symposium, Lexington, Kentucky: University of Kentucky Institute for Min-

ing and Minerals Research and Center for Applied Energy Research, p. 65.

Rutledge, James, **Hamilton-Smith, Terence**, and Young, Harvey, 1993, Micro-earthquakes shed light on Clinton County: Northeast Oil and Gas World, v. 13, no. 9, p. 12–16.

Stith, D.A., Berg, T.M., Ault, C.H., **Dever, G.R., Jr.,** Masters, J.M., Berkheiser, S.W., Jr., Simard, C.M., and Hester, N.C., 1993, Limestone and dolomite availability in the Ohio River Valley, with observations on obtaining reliable chemical analyses: Proceedings of SO_2 Capture Seminar, "Sorbent Options and Considerations," Cincinnati, Ohio, September 19–21, 1993: Washington, D.C., National Stone Association, p. 10-1–10-16.

Street, R., Taylor, K., Jones, D., **Harris, J.B.**, Steiner, G., Zekulin, A., and Zhang, D., 1993, The 4.6 $m_{b,Lg}$ northeastern Kentucky earthquake of September 7, 1988: Seismological Research Letters, v. 64, p. 187–199.

Woolery, E.W., Street, R.L., Wang, Z., and **Harris, J.B.**, 1993, Near-surface deformation in the New Madrid Seismic Zone as imaged by high resolution SH-wave seismic methods: Geophysical Research Letters, v. 20, no. 15, p. 1615–1618.

Wunsch, D.R., and Dinger, J.S., 1993, Hydrogeology and hydrogeochemistry of the Star Fire site, eastern Kentucky [abs.]: Proceedings, Kentucky Water Resources Symposium, December 16, 1993, p. 3–4.

Wunsch, D.R., and Dinger, J.S., 1994, The hydrogeology and hydrogeochemistry of the Star Fire site, eastern Kentucky: Proceedings, International Land Reclamation and Mine Drainage Conference and Third International Conference on the Abatement of Acidic Drainage, Pittsburgh, Pennsylvania, April 24–29, 1994, p. 188–197.

Wunsch, D.R., and Dinger, J.S., 1994, Hydrogeology and hydrogeochemistry of the Star Fire site, eastern Kentucky [abs.]: Proceedings, American Water Resources Association Conference, Jackson Hole, Wyoming, June 26–29, 1994.

Zhang, M., Street, R., **Harris, J.B.**, and Drnevich, V.P., 1993, A note on the influence of site conditions on ground motion values observed for the southeastern Illinois earthquake of June 10, 1987: Seismological Research Letters, v. 64, p. 149–156.

Anderson, W.H., 1993, Rocks and minerals of Kentucky: Headley–Whitney Museum, Lexington, Kentucky, July 1993.

TALKS BY STAFF MEMBERS TO PROFESSIONAL AND CIVIC GROUPS

Anderson, W.H., 1993, Rocks and minerals of Kentucky: Headley–Whitney Museum, Lexington, Kentucky, July 1993.

Anderson, W.H., 1993, Rocks and minerals of Kentucky: Mason County Soil Conservation Service Office, September 1993.

Baranoski, M.T., and **Harris, D.C.,** 1994, Play 32: Pre-Knox (Cambrian) structural and stratigraphic plays: Twenty–Fifth Appalachian Petroleum Geology Symposium, Morgantown, West Virginia, March 22, 1994.

Carey, D.I., 1993, Economics and the environment: Environmental Systems Seminar, University of Kentucky, Lexington, Kentucky, November 2, 1993.

Carey, D.I., 1993, Economics and the environment—Part 2: Environmental Systems Seminar, University of Kentucky, Lexington, Kentucky, November 9, 1993.

Carey, D.I., 1993, Quality of private ground-water supplies in Kentucky: Kentucky Water Interagency Cooperative Committee Meeting, Lexington, Kentucky, August 25, 1993.

Carey, D.I., 1993, Quality of private ground-water supplies in Kentucky: Kentucky Water Resources Symposium, University of Kentucky, Lexington, Kentucky, December 16, 1993.

Carey, D.I., 1993, Some observations on apparent relationships between ground water and surface water in the Kentucky River Basin: Kentucky Water Resources Symposium, University of Kentucky, Lexington, Kentucky, December 16, 1993.

Carey, D.I., Quality of private ground-water supplies in Kentucky: Environmental Systems Seminar, University of Kentucky, Lexington, Kentucky, April 26, 1994.

Carey, D.I., 1994, Water quality needs in the Kentucky River Basin: Kentucky River Authority, Subcommittee on Water Quality, Lexington, Kentucky, April 1, 1994.

Carey, D.I., Dinger, J.S., Davidson, O.B., Sergeant, R.E., Boone, R., Coleman, S., Ilvento, T., and Taraba, J., 1993, Quality of private ground-water supplies in Kentucky: Ohio River Basin Consortium for Research, Ninth Annual Symposium, Louisville, Kentucky, October 14, 1993.

Conrad, P.G., Dinger, J.S., and Sendlein, L.V.A., 1993, Groundwater quality and agricultural practices at two sites in Pleistocene deposits of Kentucky: Kentucky Water Resources Symposium, University of Kentucky, Lexington, Kentucky, December 16, 1993.

Conrad, P.G., Dinger, J.S., and Sendlein, L.V.A., 1993, Results for three agricultural nonpoint-source pollution study sites: Agricultural Nonpoint-Source Coordinating Committee Meeting, University of Kentucky, Lexington, Kentucky, October 7, 1993.

Conrad, P.G., Dinger, J.S., and Sendlein, L.V.A., 1994, Agricultural practices and ground-water quality at a site in the northern Mississippi Embayment, western Kentucky: American Water Resources Association Annual Summer Symposium, The Effects of Human-Induced Changes on Hydrologic Systems, Jackson Hole, Wyoming, June 29, 1994.

Conrad, P.G., Dinger, J.S., and Sendlein, L.V.A., 1994, Agricultural practices and ground-water quality in Pleistocene lacustrine deposits of a humid-temperate region [poster session]: American Water Resources Association Annual Summer Symposium, The Effects of Human-Induced Changes on Hydrologic Systems, Jackson Hole, Wyoming, June 27, 1994.

Currens, J.C., 1993, Flooding of Sinking Creek, Garretts Spring Karst Drainage Basin, Jessamine and Woodford Counties, Kentucky: Eleventh National Cave Management Symposium, Carlsbad, New Mexico, October 27–30, 1993.

Davidson, O.B., 1993, Kentucky Ground-Water Data Repository: Kentucky Water Interagency Cooperative Committee Meet-

ing, Lexington, Kentucky, August 25, 1993.

Davidson, O.B., 1993, Kentucky Ground-Water Data Repository: Ohio River Basin Consortium for Research and Education, Ninth Annual Scientific Symposium, Louisville, Kentucky, September 13–14, 1993.

Davidson, O.B., 1993, Kentucky Ground-Water Data Repository: Kentucky Water Resources Symposium, University of Kentucky, Lexington, Kentucky, December 16, 1993.

Dever, G.R., Jr., 1993, Industrial minerals: Department of Geological Sciences, University of Kentucky, Lexington, Kentucky, November 30, 1993.

Dever, G.R., Jr., 1994, Geology of the Natural Bridge State Park area: Natural Bridge State Resort Park, Slade, Kentucky, April 22, 1994.

Dinger, J.S., 1993, The balance among land use, geology, and water supplies: Earth Day Celebration, Lansdowne Elementary School, Lexington, Kentucky, September 22, 1993.

Dinger, J.S., 1993, Hydrogeology of Kentucky: Kentucky Rural Water Association, Groundwater Protection Centerpiece Workshop, Frankfort, Kentucky, February 15, 1994.

Drahovzal, J.A., 1993, The East Continent Rift Basin: Illinois Geological Society and Indiana–Kentucky Geological Society, Grayville, Illinois, October 22, 1993.

Drahovzal, J.A., 1994, Basin-floor fan complexes in Cambrian rift basins of Kentucky: American Association of Petroleum Geologists Annual Meeting, Denver, Colorado, June 14, 1994.

Drahovzal, J.A., 1994, The structure, stratigraphy, and future hydrocarbon potential of the Rome Trough in Kentucky: Twenty–Fifth Annual Appalachian Petroleum Geology Symposium, Morgantown, West Virginia, March 22, 1994.

Drahovzal, J.A., and Wickstrom, L.H., 1993, The East Continent Rift Basin: American Association of Petroleum Geologists, Hedberg Research Conference on Basement and Basins of Eastern North America, University of Michigan, Ann Arbor, Michigan, November 17, 1994.

Eble, C.F., 1993, Coal balls: Bluegrass Gem and Mineral Society, Lexington, Kentucky, May 23, 1993.

Eble, C.F., 1993, Coal: Its origin, composition, and future: Coal in the Classroom Seminar, Lexington, Kentucky, November 4, 1993.

Eble, C.F., 1993, Coal: Its origin, composition, and future: Alice Lloyd College, Pippa Passes, Kentucky, November 9, 1993.

Eble, C.F., 1993, The science of coal: Elderhostel, Frankfort, Kentucky, July 19, 1993.

Eble, C.F., 1994, Carboniferous palynology: Kentucky Paleontological Society, Lexington, Kentucky, March 31, 1994.

Hamilton-Smith, Terence, 1993, GIS (Geographical Information System) evaluation of fractured High Bridge reservoirs: Clinton County Oil and Gas Advisory Committee Meeting, Albany, Kentucky, July 29, 1993.

Hamilton-Smith, Terence, 1994, Fractured Devonian shale gas reservoirs of the Appalachian Basin: Twenty-Fifth Appalachian Petroleum Geology Symposium, Morgantown, West Virginia, March 22, 1994.

Hamilton-Smith, Terence, 1994, Gas production from the New Albany Shale of the Shrewsbury Field: Indiana–Kentucky Geological Society Meeting, Owensboro, Kentucky, January 27, 1994.

Haney, D.C., 1993, Trends and opportunities in the profession of geology: University of Kentucky Department of Geology Centennial Seminar, Lexington, Kentucky, October 1993.

Hampson, S.K., **Keagy, D.M., Dinger, J.S.**, and Sendlein, L.V.A., 1993, The impact of agricultural practices on the shallow subcutaneous ground water in the Inner Blue Grass Region in Kentucky: Kentucky Water Resources Symposium, University of Kentucky, Lexington, Kentucky, December 16, 1993.

Harris, D.C., 1993, Regional subsurface stratigraphy and petrology of the Newman Limestone, Appalachian Basin, Eastern Kentucky—A project proposal: Oil Industry Representatives, Lexington, Kentucky, July 13, 1993.

Harris, D.C., 1994, Lithostratigraphy and hydrocarbon potential of the Conoco No. 1 Turner well, McLean County, Kentucky: Ohio–Kentucky Geological Society, Owensboro, Kentucky, March 29, 1994.

Harris, D.C., 1994, Lithostratigraphy and hydrocarbon potential of the Conoco No. 1 Turner well, McLean County, Kentucky: Illinois State Geological Survey, Champaign, Illinois, May 9, 1994.

Harris, D.C., 1994, Lithostratigraphy and hydrocarbon potential of the Conoco No. 1 Turner well, McLean County, Kentucky: Kentucky Oil and Gas Association Annual Meeting, Owensboro, Kentucky, June 15, 1994.

Harris, D.C., 1994, The Rose Run Sandstone in Kentucky: Is there potential south of the Ohio?: Ohio Section, Society of Petroleum Well Log Analysts, Canton, Ohio, November 18, 1993.

Harris, D.C., 1994, The Rose Run Sandstone in Kentucky: Is there potential south of the Ohio?: Appalachian Geological Society, Charleston, West Virginia, January 18, 1994.

Harris, J.B., Woolery, E.W., and Wang, Z., 1994, A shallow seismic investigation of Quaternary deformation on the Lake County Uplift, central New Madrid Seismic Zone: Geological Society of America, South-Central Section Annual Meeting, Little Rock, Arkansas, March 22, 1994.

Heazlit, T.J., 1993, Karst, ground water, and the environment: Morton Middle School, Lexington, Kentucky, October 1993.

Heazlit, T.J., 1994, The effect of siltation on cave and karst environments: U.S. Forest Service, Horse Lick Creek Management Planning Meeting, Berea Ranger District, June 15, 1994.

Humphreys, Matthew, and Watson, A.E., 1994, Middle Ordovician St. Peter Sandstone gas: Play 30: Twenty-Fifth Annual Appalachian Petroleum Geology Symposium, Morgantown, West Virginia, March 22, 1994.

Kiefer, J.D., 1994, The geologic history of the McConnell Springs area, Lexington: Lexington Public Library, Symposium on the History of McConnell Springs, Lexington, Kentucky, February 1, 1994.

Kiefer, J.D., 1994, The geology and hydrogeology of Georgetown's Royal Spring: Scott County Historical Society, Georgetown, Kentucky, May 14, 1994.

Kiefer, J.D., 1994, The importance of ground water to Kentucky: Kentucky League of Women Voters–U.S. Environmental Protection Agency National Teleconference on Ground Water, Eastern Kentucky University, Richmond, Kentucky, May 4, 1994.

Kiefer, J.D., 1993, Information on Kentucky available to earth-science teachers: National Science Teachers Association regional convention, Louisville, Kentucky, November 11, 1993.

Kiefer, J.D., 1994, Progress since the passage of the Kentucky Solid Waste Management Act of 1991: University of Kentucky Seminar on Solid Waste Management, Lexington, Kentucky, March 3, 1994.

Kiefer, J.D., 1994, A summary of legislative action on environmental issues during the 1994 Kentucky legislative session: Fayette County Environmental Commission, Lexington, Kentucky, May 1, 1994.

Kipp, J.A., 1993, Environmental stewardship: St. Thomas Lutheran Church Youth Group, Richmond, Kentucky, October 24, 1993.

Kipp, J.A., 1993, The GAIA hypothesis as related to the influence of biota on the hydrosphere: Woodford County High School, Versailles, Kentucky, November 18, 1993.

Kipp, J.A., 1993, Karst hydrology in Woodford County: Woodford County High School, Versailles, Kentucky, December 13, 1993.

Kipp, J.A., 1993, The Knox aquifer in central Kentucky: U.S. Soil Conservation Service Regional Training Session, Cynthiana, Kentucky, November 11, 1993.

Kipp, J.A., 1994, Water quantity and distribution, and sink hole management: Water Resource Management Seminar, Maysville Community College, Maysville, Kentucky, February 24, 1994.

Kipp, J.A., Minns, S.A., Wunsch, D.R., and Dinger, J.S., 1993, Hydraulic conductivity of coal-bearing rocks in southeastern Kentucky: Kentucky Water Resources Symposium, University of Kentucky, Lexington, Kentucky, December 16, 1993.

Lovins, E.E., and Heazlit, T.J., 1993, Mountain formation and recreation: Breckinridge Elementary School, Lexington, Kentucky, December 1993.

Meglen, J.F., and Noger, M.C., 1994, Lower Devonian–Upper Silurian unconformity play: Twenty-Fifth Annual Appalachian Petroleum Geology Symposium, Morgantown, West Virginia, March 22, 1994.

Meglen, J.F., Noger, M.C., Humphreys, Matthew, and Baranoski, M.T., 1994, Upper Silurian Lockport Dolomite–Keefer (Big Six) Sandstone play: Twenty-Fifth Annual Appalachian Petroleum Geology Symposium, Morgantown, West Virginia, March 22, 1994.

Minns, S.A., 1993, Concepts of ground-water flow in the Eastern Kentucky Coal Field: Kentucky Water Resources Research Institute hydrology luncheon seminar, Lexington, Kentucky, September 1, 1993.

Minns, S.A., 1993, Concepts of ground-water flow in the Eastern Kentucky Coal Field: Kentucky Water Resources Symposium, University of Kentucky, Lexington, Kentucky, December 16, 1993.

Minns, S.A., 1993, Effects of deep coal mines on hydrogeology and general ground-water concepts for eastern Kentucky: Sixth Annual Kentucky Professional Engineers in Mining Seminar, Lexington, Kentucky, August 13, 1993.

Minns, S.A., 1994, Effects of coal-ash disposal on ground-water

systems at three sites in Kentucky: University of Kentucky Department of Geological Sciences Alumni Weekend Seminar, Lexington, Kentucky, April 23, 1994.

Nuttall, B.C., 1994, Play 28: The Upper Ordovician "Trenton" Limestone: Twenty-Fifth Annual Appalachian Petroleum Geology Symposium, Morgantown, West Virginia, March 22, 1994.

Nuttall, B.C., Hamilton-Smith, Terence, Humphreys, Matthew, Meglen, J.F., and Drahovzal, J.A., 1994, Natural gas resources of the Appalachian Basin region of eastern Kentucky: American Association of Petroleum Geologists Annual Meeting, Denver, Colorado, June 14, 1994.

Nuttall, B.C., and Humphreys, Matthew, 1994, Review of Kentucky drilling activity: Fifty-Eighth Annual Meeting of the Kentucky Oil and Gas Association, Owensboro, Kentucky, June 15, 1994.

Weisenfluh, G.A., 1994, Applications of geographic information systems to coal resource assessments: University of Kentucky Department of Geological Sciences Seminar Series, Lexington, Kentucky, February 3, 1994.

Wunsch, D.R., 1993, Environmental geology: Youth Engineering Workshop, Department of Civil Engineering, University of Kentucky, Lexington, Kentucky, July 14, 1993.

Wunsch, D.R., and Dinger, J.S., 1993 Hydrogeology and hydrogeochemistry of the Star Fire site, eastern Kentucky: Kentucky Water Resources Symposium, University of Kentucky, Lexington, Kentucky, December 16, 1993.

Wunsch, D.R., and Dinger, J.S., 1994, The hydrogeology and hydrogeochemistry of the Star Fire site, eastern Kentucky: International Land Reclamation and Mine Drainage Conference and Third International Conference on the Abatement of Acidic Drainage, Pittsburgh, Pennsylvania, April 24–29, 1994.

Wunsch, D.R., and Dinger, J.S., 1994, Hydrogeology and hydrogeochemistry of the Star Fire site, eastern Kentucky: American Water Resources Association Conference, Jackson Hole, Wyoming, June 26–29, 1994.

PERSONNEL

Professional Staff

Warren H. Anderson, M.S.
Geologist IV, Coal and Minerals Section

Robert E. Andrews, B.S.
Geologist I, Coal and Minerals Section

Daniel I. Carey, Ph.D.
Hydrologist IV, Water Resources Section

X. Mara Chen, Ph.D.
Post-Doctoral Scholar, Petroleum and Stratigraphy Section

Donald R. Chesnut, Jr., Ph.D.
Acting Head, Coal and Minerals Section

James C. Cobb, Ph.D.
Assistant State Geologist

Philip G. Conrad, M.S.
Geologist II, Water Resources Section

Steven J. Cordiviola, M.S.
Head, Computer and Laboratory Services Section

James C. Currens, M.S.
Geologist IV, Water Resources Section

O. Barton Davidson, M.S.
Geologist II, Water Resources Section

Garland R. Dever, Jr., M.S.
Geologist VII, Coal and Minerals Section

James S. Dinger, Ph.D.
Head, Water Resources Section

Joseph B. Dixon, B.S.
Systems Programmer, Computer and Laboratory Services Section

James A. Drahovzal, Ph.D.
Head, Petroleum and Stratigraphy Section

Cortland F. Eble, Ph.D.
Geologist V, Coal and Minerals Section

Alex W. Fogle, M.S.
Hydrologist III, Water Resources Section

Henry E. Francis, B.S.
Associate Scientist, Computer and Laboratory Services Section

Patrick J. Gooding, M.S.
Geologist IV, Petroleum and Stratigraphy Section

Stephen F. Greb, Ph.D.
Geologist III, Coal and Minerals Section

James L. Hamilton, M.P.A.
Administrative Staff Officer II

Terence Hamilton-Smith, M.S.
Geologist V, Petroleum and Stratigraphy Section

Donald C. Haney, Ph.D.
State Geologist and Director

David C. Harris, M.S.
Geologist IV, Petroleum and Stratigraphy Section

James B. Harris, Ph.D.
Postdoctoral Scholar, Petroleum and Stratigraphy Section

John K. Hiett, B.S.
Geologist I, Coal and Minerals Section

Terry D. Hounshell
Chief Cartographic Illustrator, Publications Section

Matthew Humphreys, M.S.
Geologist II, Petroleum and Stratigraphy Section

Donald W. Hutcheson, M.S.
Head, Publications Section

Dwayne M. Keagy, M.S.
Geologist II, Water Resources Section

John D. Kiefer, Ph.D.
Assistant State Geologist

Gerald J. Kinsella, B.S.
Geologist I, Petroleum and Stratigraphy Section

James A. Kipp, M.S.
Geologist V, Water Resources Section

Joseph F. Meglen, M.S.
Geologist II, Petroleum and Stratigraphy Section

Shelley A. Minns, Ph.D.
Geologist II, Water Resources Section

Martin C. Noger, B.S.
Geologist VII, Petroleum and Stratigraphy Section

Brandon C. Nuttall, B.S.
Geologist IV, Petroleum and Stratigraphy Section

Richard E. Sergeant, M.S.
Geologist V, Computer and Laboratory Services Section

Margaret Luther Smath, B.A.
Geologic Editor III, Publications Section

Richard A. Smath, M.S.
Geologist III/ESIC Coordinator, Publications Section

Thomas N. Sparks, M.S.
Geologist I, Petroleum and Stratigraphy Section

Anna E. Watson, B.S.
Geologist I, Petroleum and Stratigraphy Section

Gerald A. Weisenfluh, Ph.D.
Geologist IV, Coal and Minerals Section

David A. Williams, M.S.
Geologist V, Coal and Minerals Section (Henderson Office)

David R. Wunsch, Ph.D.
Geologist IV, Water Resources Section

Technical Staff

Karen Cisla, B.S.
Senior Research Analyst, Computer and Laboratory Services Section

Xenia P. Culbertson, M.A.
Research Analyst, Computer and Laboratory Services Section

Robert R. Daniel
Laboratory Technician B, Petroleum and Stratigraphy Section

Ed Fortner, Jr.
Geological Technician, Water Resources Section

C. Douglas R. Graham, B.S.
Geological Technician, Water Resources Section

Tammie J. Heazlit, B.S.
Senior Laboratory Technician, Computer and Laboratory Services Section

Robert C. Holladay
Principal Drafting Technician, Publications Section

Eric E. Lovins, M.S.
Research Analyst, Computer and Laboratory Services Section

Steven R. Mock, M.S.
Senior Laboratory Technician, Computer and Laboratory Services Section

Tim Montowski, B.S.
Geological Technician, Water Resources Section

Michael L. Murphy
Principal Drafting Technician, Publications Section

Jay C. Ramsey, B.S.
Laboratory Assistant, Petroleum and Stratigraphy Section

Gwenda K. Rulo
Drafting Technician, Publications Section

Mark F. Thompson, B.S.
Research Analyst, Computer and Laboratory Services Section

Kevin J. Wente, B.S.
Geological Technician, Water Resources Section

Clerical Staff

Roger Banks, B.S.
Account Clerk V, Personnel and Finance Section

Joyce Belcher
Staff Assistant VI, Personnel and Finance Section

Frances Benson
Staff Assistant IV, Petroleum and Stratigraphy Section

William A. Briscoe, III
Publications Sales Supervisor, Publications Section

Luanne Davis
Staff Assistant IV, Petroleum and Stratigraphy Section

Shirley D. Dawson
Staff Assistant V, Publications Section

Theola L. Evans
Staff Assistant IV, Petroleum and Stratigraphy Section

Jody L. Fox
Staff Assistant VII, Personnel and Finance Section

Regina A. Gibson
Staff Assistant VII, Personnel and Finance Section

Eugenia E. Kelley
Staff Assistant V, Petroleum and Stratigraphy Section

Kenneth G. Otis
Stores Worker, Publications Section

Margaret E. Reed
Data Entry Technician, Coal and Minerals Section

Juanita G. Smith
Staff Assistant V, Personnel and Finance Section (Henderson Office)

Kimberly B. Stroth
Staff Assistant IV, Petroleum and Stratigraphy Section

Affiliated Researchers

William Evangelou, UK Agronomy Department

Gary Felton, UK Department of Agricultural Engineering

Lyle V.A. Sendlein, UK Department of Geological Sciences, Director of the Institute for Mining and Minerals Research, Director of the Kentucky Water Resources Research Institute

Ronald L. Street, UK Department of Geological Sciences

Joseph L. Taraba, UK Department of Agricultural Engineering

Bill Thom, UK Agronomy Department

Grant Thomas, UK Agronomy Department

Richard Warner, UK Department of Agricultural Engineering

Anne D. Webster, UK Anthropology Department

Ken Wells, UK Agronomy Department

William Witt, UK Agronomy Department

Student Assistants

Michelle K. Barfield
John C. Boone
Orian C. Caldwell, IV
Mary A. Cawood
Arnold Lee Coffee, Jr.
Jarrod L. Combs
Edgar K. Cross, Jr.
Joseph D. Cupp
Walter W. Davis
Bryan A. Eklund
Christopher Elvrum
Anil S. Giovindappa
Cindy R. Greenwell
D. Krista Gremos
Steven K. Hampson
Jonathan S. Hoyle
Scott E. Justice
Yue Jin Liu
Jon C. Lowry
Christopher A. Martin
Harold L. McGuffey
John J. Michaels
Elizabeth A. Miller
Angela M. Moore
Christopher Moore
Garry L. Mounce
Gordon T. Mullins
Pramod R. Pateel
Carl Petersen
Emily M. Reichert
William T. Schick
Hai Shen
Birinder S. Shergill
Nicholas S. Sirek
Jeffery D. Snell
Sri Kanta Srikantapura
Page B. Taylor
Ernest E. Thacker
Ian D. Thomas
Matt Varney
Zhenming Wang
Mark J. Warrell
Thomas M. Whitsett
John D. Whittler
Richard M. Williams
Edward W. Woolery
William J. Young
Yunhe Zhang

QUANTITATIVE MEASURES OF KGS ACTIVITY FOR 1993–94

Public requests answered		9,132
Coal and minerals	1,809	
Water	555	
Petroleum	6,337	
Computer and analytical	431	
	9,132	
Well Record Library inquiries		3,699
Phone	1,708	
Visitors	1,991	
	3,699	
Well logs copied		25,615
Electronic-data disks	73	
Well-location overlays	644	
Wells processed		1,375
Wells computerized	2,210	
Ground-Water Data Repository		348
(Operational since October 1992)		
Publication Sales		50,000
Maps sold	20,000	
Publications sold	4,000	
Well records	26,000	
Earth Science Information Center requests		565
Map requests	203	
Geodetic control	137	
Aerial-photo information	73	
Digital map information	28	
Publication information	124	
Editorial, manuscripts processed		164
KGS publications	16	
Journal/symposium articles	75	
Abstracts/other papers	73	
Committees, boards, societies		62
National	20	
State	16	
UK	20	
Local	6	
Talks to civic and professional groups		183
Papers to symposiums and journals		63
Visits to schools, mineral shows, and science fairs		90
Academic		
Graduate committees	11	
Ph.D.	6	
M.S.	5	
Classes and short courses taught	64	
Grants and contracts in force		19
State and Federal grants: 12 active, totalling $1,149,936/year		
Grants with other units of UK: 7 active, totalling $546,932/year		
New awards: 5 total		
Conferences, symposia, and field trips sponsored		3
Well Sample and Core Repository visitors		69
Inquiries	977	
Cores sampled	130	
Core data provided	300	
Topographic map revisions		34